SUSTAINABLE UTILIZATION OF WOODFUEL IN SELECTED RURAL SITES OF MWALA SUB-COUNTY, MACHAKOS COUNTY, KENYA

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DECLARATION

I understand that plagiarism is an offence and I therefore declare that this thesis is my original work and has not been presented to any other institution for any other award**.**

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DEDICATION

To my wife Eunice, our children Mercy and Eric and my pastor Rev. Agnes Nzomo for their immense moral and Spiritual support. To God be all the Glory as we grow to be a stronger God fearing family.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACTS	African Centre for Technology Studies
ERDG	Energy Research and Development Group
FAO	Food Agriculture Organization
IEA	International Energy Agency
LPG	Liquefied Petroleum Gas
NEMA	National Environment Management Authority
SEKU	South Eastern Kenya University
SPSS	Statistical Package for Social Sciences.
WECS	Water and Energy Commission Secretariat
WHO	World Health Organization
MoE	Ministry of Environment
GHG	Green House Gases

DEFINITION OF TERMS

Wood fuel: Includes all types of biofuel derived directly and indirectly from trees and shrubs grown on forest and non-forest land (FAO, 2004).For the purpose of this research wood fuel is taken to mean firewood.

Fuel wood: It includes wood in the rough form and in small pieces, chips pellets and powder derived from forests and isolated trees, as well as wood by products from the timber industry and recovered wood products (Rural Focus 21, 2011).

Rationing: It refers to an artificial control on the distribution of scarce resources (m.economictimes.com). In the context of this research, it involves rationing of wood fuel.

Bundle of wood: For the purpose of this research a bundle of wood was taken to mean a collection of dry wood weighing 20 Kg at 12%-15%moisture content efficient and does not produce smoke. It can use both wood and charcoal. It costs between Ksh. 4000 and Ksh.5000.

ABSTRACT

Many of the rural households use traditional stoves which have low energy efficiency leading to wastage of wood fuel. This study focused on understanding the sustainable utilization of wood fuel in two (2) sub-locations namely Mwala and Kibauni. The primary objective of this study was to establish if wood fuel utilization styles by the households in the study areas is sustainable. The specific objectives of the study were to: document the types of cooking stoves used by households in the study areas, establish the level of adoption of the energy saving measures and explore other alternative energy sources which the residents use to complement wood fuel. This study used survey methodology and observation to collect data. The total household sample size was 160 respondents. Data collection instrument for this research was questionnaires. Data was analyzed using descriptive statistics and inferential statistics and the software was Statistical Package for Social Sciences (SPSS) version 23. From the findings of the research the traditional three stone stoves was the most popular stove, in Mwala having 93% of the respondents using it and Kibauni 96%. There was significant relationship between the type of stove and the number of days taken to consume one 20kg bundle of dry wood (df=1 and 158, F=8.187, p=0.005).The study revealed low adoption of rationing of wood with majority of the respondents, i.e 84% in Kibauni and 65% in Mwala not practicing it. There was significant relationship between rationing of woodfuel and the number of days taken to consume a bundle of 20 kg of dry wood (df=1 and 158, F=462.898, p=0.00). The study also revealed low adoption of splitting of wood with 70% of respondents in Mwala and 88% in Kibauni not doing the splitting. There was low adoption of putting off fire after use with 66% of respondents in Mwala and 81% in Kibauni not practicing it. The study revealed a significant relationship between putting off fire after use and the number of days taken to consume one bundle of 20 kg of dry wood (df=3 and 156, F=57.292, p=0.00). In alternative energy sources like biogas, solar and electricity majority of the households did not have any with 67% of households in Mwala and 57% in Kibauni reporting to have none of the mentioned alternative energy sources. The study recommended that aggressive campaign in dissemination of improved stoves and related technology in order to reduce pressure on forests and embrace energy saving measures like rationing wood, splitting wood and putting off fire after use. It also recommended subsidizing of electricity connection and assistance of the Government to enable the households install biogas and solar power.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

In the developing world, meals are cooked and homes are treated with homemade traditional stoves or open fires. These stoves are fired with either biomass fuels, such as wood, branches, twigs, dung or coal. When these are not available, agricultural residues or even leaves and grass are used. The smoke emitted from such stoves is made up of particles and gaseous chemicals. It is estimated that about 70% of households in developing countries use fuels such as wood, dung and crop residues for cooking (International Energy Agency, 2002; WHO, 2006).

In Kenya about 90% of rural households use wood fuel either as firewood or charcoal (MoE, 2002). Wood fuel meets over 93% of rural household energy needs whilst charcoal is the dominant fuel in urban households (Theuri, 2002; Kituyi, 2008). Besides being the standard cooking fuel for the majority of Kenyan households, wood fuel is also an important energy source for small-scale rural industries used for tobacco curing, tea drying, brick making, fish smoking and bakeries among others (Githiomi, 2010). Wood energy is highly utilized by majority of citizens and owing to increasing demand for agricultural land to curb food insecurity, supply of wood fuel has gone down. At the national level there has been no proper planning and policies governing utilization of this essential renewable energy.

The fact that wood fuel is available naturally, it makes it a primary fuel source for mankind. It is important to realize that utilization of wood fuel by mankind has become an environmental issue that needs attention if sustainable development goals are to be attained. The traditional stoves are known to be very inefficient and wasteful interms of biomass usage. The energy output is low and much of smoke produced as a result of incomplete combustion is responsible for respiratory complications among young children have been victims. Traditional fuels, normally available locally at low or no cost, are characterized by low combustion efficiency of 10% (Kammen, 1995). Poor combustion efficiency leads to emission of carbon dioxide **(**CO_2**)**, methane (CH_4) and nitrous oxide (N_2O) causing an increase in Green House Gases (GHG) when the rate of consumption of biomass is higher than its replacement (Sanga and Jannuzi, 2005).According to the latest Global Burden of Disease estimates, use of biomass fuels is now the second leading risk factor for ill health in developing countries. The World Health Organization (2002) estimated that 1.5 million premature deaths per year are directly attributable to indoor air pollution from the use of solid fuels. That is more than 4 000 deaths per day, more than half of them children under five years of age.

The inefficiency of the traditional stoves have resulted to deforestation given that in highly populated regions much of wood fuel is required for household heating purposes and maintain the stoves in operation. Furthermore wood collection exercise requires time and labor and this has implied negatively to children who end up missing useful time in school. Again involving women a lot in wood fuel collection is a culture of many tribes in Kenya and these impacts negatively on gender equity. The heavy loads carried by women on their heads and backs may cause spinal injuries and the long time spent can be used for other productive activities such as doing business and attending to their farms. The average fuel wood load in sub-Saharan Africa is around 20 kg but loads of 38 kg have also been recorded (Rwelamira, 1999).

A study by World Agroforestry Centre 2014, on firewood utilization patterns, several challenges hinder sustainable access and utilization of firewood such as the imbalance between supply and demand, gender inequality and knowledge gaps. This study revealed that in rural Kenya, firewood is generally sourced from farmlands, private/public plantations or indigenous forests where tree by-products such as pruned branches from forest plantations or fallen pieces of wood are collected. There has been a shortage of wood fuel in many parts of Kenya (Ngugi, 1988). This high demand causes people to turn to nearby forests for firewood and charcoal thus leading to deforestation and soil erosion (Wanambwa, 2005).

Wood collection especially from indigenous forests is guided by some legal framework. Kenya Forest Service licenses collection by determining the amount collected, tree species and sizes to be cut and the types of tools to be used to cut the wood. Illegal tree harvesting and encroachment of human activities has been witnessed in many forests and this has been due to weak system of enforcing the forest regulations. There has been some localized deforestation, but depletion of forest cover on a large scale has not been found to be attributable to demand for fuel wood (Arnold *et al*., 2003).

Firewood collection and utilization is an activity which has formed part of tradition of man but it has never been brought on board for consideration by policy maker, researchers and development practitioners. This means that the field lacks knowledge to be used as a benchmark to help propel nations to sustainable utilization of wood fuel. For instance multipurpose tree species found in different ecological zones have not been mapped and availing knowledge to end users of energy efficient technologies is still a challenge to most nations. Data on good practices as well as funding and enforcement of existing bioenergy policies and regulations remains a challenge (World Agroforestry Centre, 2014).

Environmental movements have been campaigning for use of renewable energy sources such as solar, wind and hydro power since they do not harm the environment, can't be depleted and so they can be utilized in the foreseeable future. The increasing global demand for energy calls for sustainable energy sources such that nations can focus on energy conservation as a means of complementing energy development. The acquisition and use of wood fuel energy conservation technologies is very important for Kenya to be able to decrease demand on wood fuel and tackle the problem of deforestation.

1.2 Statement of the Problem

In Mwala Sub County, about 90% of the residents use wood energy for their household heating purposes (MoE, 2002). The high demand of firewood for both household and institutional needs has impacted negatively on the vegetation which in turn has led to global warming, soil degradation and scarcity of water. Most households and institutions lack information on energy saving stoves and sufficient education on energy saving stoves which could help reduce their energy demand (Makame, 2006).

1.3 Justification of the Study

The findings of this study will establish how wood energy is utilized by households in Mwala subcountyand if the utilization is sustainable or not. In addition, the study will help households of Mwala to apply the right conservation measures in usage of fuelwood for the sake of our future generation. Households will be in a position to utilize wood energy effectively and sustainably and forest cover will therefore be enhanced in line with government policy of 10% forest cover in Kenya.

When wood energy is effectively utilized and conserved, soil will be conserved, farming will be promoted, hence high food production in Mwala sub-county. Proper and sustainable energy use will prevent rampant cutting of trees which will lead to attraction of rain hence availability of water and high crop yields.

1.4 Objectives of the Study

1.4.1 General Objective

The general objective of the study was to establish whether wood fuel utilization methods by the households in Mwala and Kibauni sub locations are sustainable.

1.4.2 Specific Objectives

The specific objectives were:

1. To document the common types of cooking stoves used by households in selected sites of Mwala sub-county.
2. To establish the level of adoption of energy saving measures in the study areas.
3. To explore other alternative energy sources that can be used by residents in the study area to reduce over dependence on wood fuel in cooking.

1.4 Research Questions

This study was guided by the following research questions

1. Which types of cooking stoves do the households in the study areas commonly use?
2. Which are the levels of adoption of energy saving measures?
3. Which other alternative energy sources can the residents in the study area adopt to complement wood fuel?

1.5 Conceptual Framework

Mugenda and Mugenda (2003) defined a conceptual framework as a hypothesized model identifying the model under study and the relationship between the dependent and independent variables. Independent variable is the variable which the experimenter manipulates (Saul, 2008). It is assumed to have a direct effect on the dependent variable.

The independent variables in this study was the type of cooking stoves(Traditional 3 Stone stove and the improved stoves), and energy saving measures which included rationing of wood, putting off fire after use and splitting of firewood.

Dependent variable is the variable the experimenter measures, after making changes to the independent variable. The dependent variable was sustainable utilization whose indicator was the number of days taken to utilize fully one bundle of 20 kg of dry wood of moisture content 12% - 15%.

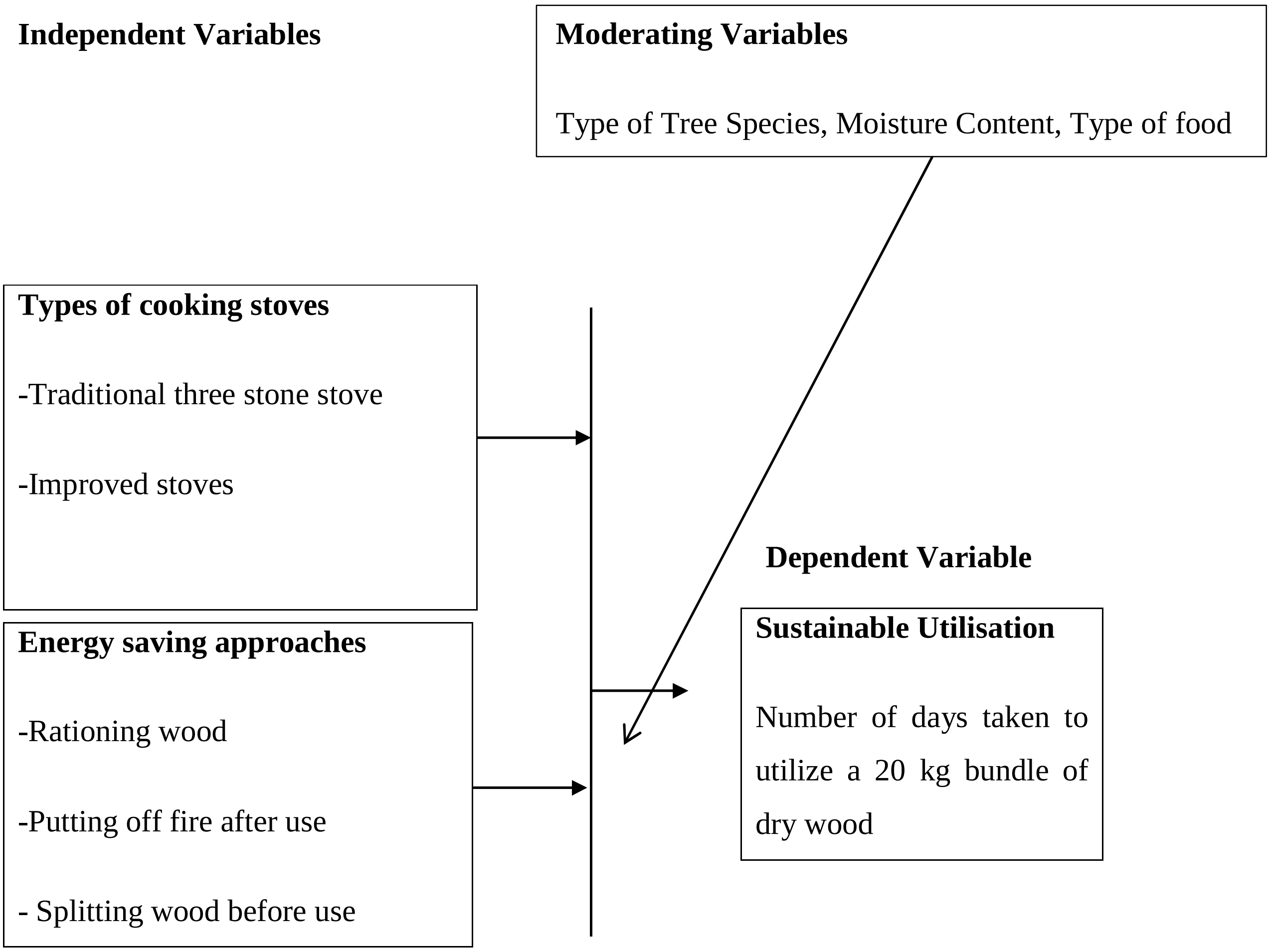


Figure 1.1: Conceptual framework

1.6 Limitation of the Study

In the study no particular plant species was considered but instead the researcher used a general approach for all plant species commonly used by households for woodfuel.

1.7 Delimitations of the Study

This study was carried out in Mwala and Kibauni sub locations of Mwala Sub-county in Machakos County. The study specifically focused on those households in Mwala that are in the rural areas and not the ones in Mwala town. The reason behind this was that wood energy is majorly used in the rural areas than in urban centers. It also focused on those households that prepare their daily meals at home other than purchasing ready prepared food from food sellers.

1.8 Assumptions

The wood fuel considered in this study during the process of data collection was assumed to be at 12%-15% moisture content. This was based on the fact that data collection was done during a hot dry spell in July and that respondents confessed that dry wood is preferred because of its good ignition property.

1.9 Theoretical Framework

The fuel wood gap theory, formulated in the 1970s, implied that wood fuels were consumed on a non-sustainable basis. The gap indicated that in many countries consumption was larger than the sustainable supply from forest land. It was then concluded that deforestation and forest degradation were largely due to wood fuel harvesting. This, raised a lot of concern among national and international agencies regarding the future of forests.

When the fuel wood gap theory was proposed data on the origins of wood fuel were scarce and it was assumed that that all wood fuel originated from forests. However, now that much more data have become available, an entirely different picture has emerged. We now know that the majority of wood fuel, originates from non-forest sources and the supply from these non-forest sources appear to be sufficient to fill the gap. The foregoing implies that wood fuel harvesting from forest land is not necessarily non-sustainable, and that wood fuel use is not necessarily linked to deforestation. Mahiri, (1998) using aerial photographs and spot images covering Nyando Division showed both spatial and temporal change in the woody biomass. The study indicated a general shift of the woody vegetation from the original bushland to concentrations around settlement. It was therefore revealed that much of natural bush has disappeared giving way to increased settlements and Agricultural frontiers.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Wood fuel Situation

Wood fuel includes all types of biofuels derived directly and indirectly from trees and shrubs grown on forest and non-forest land. Fuel wood (firewood) includes wood in the rough form in small pieces, chips, pellets and powder derived from forests and isolated trees, as well as wood by products from the timber industry and recovered wood products. Charcoal on the other hand refers to a solid residue derived from the carbonisation, distillation, pyrolysis and torrefaction of wood (trunks and branches of trees) and wood by-products, using continuous or batch systems i.e. pit, brick and metal kilns (Ndengwa *et al*, 2011).Wood fuel quite accessible by many people and again it has many uses. Consequently, it has been relied on all over the world for household and industrial applications. However the level of use differs from one country to another owing to the fact that many countries have embarked to use other types of fuel like nuclear and oil which can produce more energy to propel the transport, commercial and industrial sectors.

2.1.1 Global Wood fuel Situation

Asia and Africa produces over 75% of the wood fuel (Emily, 2001). The total production of wood in 2000 reached approximately 3.9 billion cubic meters of which 2.3 billion cubic meters was used for wood fuels. This means that approximately 60% of the world's total wood removals from forests and trees outside forests are used for energy purposes (FAO, 2008). Thus it is very important for efforts to be made in order to reduce the demand on wood biomass and thus conserve the forests and the environment. The projections of global wood fuel consumption by 2010 ranged from 1.5 billion m^3 (a decrease of 16% from 1998 levels) to 4.25 billion m^3 (an increase of 136%) (Brooks, 1996).

2.1.2 Global Wood fuel Consumption

According to best estimates, total wood fuel consumption in Africa amounted to 630 million m^3 in 1995. Compared to wood fuel consumption in other continents (or group of countries), Africa was an intermediate consumer in 1980, 1985 and 1990 (FAO, 1999).Renewable energy account for about 13.3% of the world's total primary energy and it is believed that it will play an increasingly important role in energy supplies in both developing and developed societies in the future. Biofuels amount to almost 80% of the total renewable energy supplying more energy than nuclear sources, and about four times as much as hydropower, wind, solar, and geothermal energy combined. About 75% of biofuels are derived from wood fuel (Andrew, 2011).

Primary solid biomass (wood) accounts for almost 10% of the world's total energy production (Sims *et al.,* 2007). The percentage for developing countries is much higher, ranging from 13.5 percent of total energy production in Latin America to 19 percent in Asia and 26.2% in Africa. About 36 EJ of the energy obtained from solid biomass is collected as wood fuels from forests and trees outside forests in developing countries, of which about 3 EJ is used for charcoal production. The world's wood fuel production amounted to 1.89 billion m3 in 2007, almost 53 percent of the world's total wood production (FAO, 2009).

Quantities of wood fuel consumed per person vary considerably between regions. In respect to the regions, sub-Saharan and South Africa are the most important wood fuel consumers estimates an average fuel wood consumption of $0.99m^3$/ person per year for Central Africa, whereas in African dryland consumption is only about half, given the scarcity of the resource (FAO,2012).

2.1.3 Wood fuel Situation in Developing Countries

In Africa over 90% of the wood taken from forests is wood fuel. The majority is consumed directly as fuel wood, however, a varying but substantial amount is transformed into charcoal. More than 80% of it is used in rural areas making charcoal the most important source of household energy in many African cities (Seidel, 2008 and Amour, 1997). There will be a greater demand for wood fuel by the year 2030 in Africa and yet there is shortage in its supply currently. Thus there is need for adoption of technologies that minimize wood fuel consumption in order to make its usage sustainable and also encourage afforestation and re-afforestation (Arnold and Pearson (2003).

Demand for fuelwood and charcoal is driven primarily by growing numbers of rural poor, who depend on wood for their cooking and heating needs. Charcoal is also an important fuel among the rural population, whose numbers are expanding rapidly. According to Mangat, (2009), statistics provided by Camco Global shows that wood fuel is one of the major causes of environmental degradation and accounts for about 18% of the world's greenhouse gases (GHG).

The International Energy Agency estimated that the number of people using fuelwood and other biomass fuel in Africa will rise by more than 40% between 2000 and 2030 to about 700 million and that in the latter years there will still be about 1.7 billion users in Asia (IEA, 2002). This has a serious implication on emission of GHGs unless efforts are made to adopt improved stoves in order to improve efficiency, reduce demand of biomass fuel from forests and thus mitigate against global warming and climate change.

Most households in developing countries use traditional stoves such as the three stone and the metallic charcoal stoves which are less efficient in energy conservation. Many Sub-Saharan African countries share the problem of over-exploitation of wooden lands. Vast areas that were once highly productive in terms of biomass yield have been completely depleted. Estimates indicate that over 11 million hectares of tropical forests are lost annually under excessive clearance and mismanagement (Sokona, 2008). Excessive clearance of forests removes ground cover making the land prone to soil erosion thus accelerating land degradation.

2.1.4 Wood fuel Situation in Kenya

The biomass demand in Kenya is estimated at 40.5 million tonnes against a sustainable supply of 16 million tonnes (Kamfor, 2002). A big percentage of households in Kenya derive their household energy from biomass inform of firewood or charcoal.

Firewood and charcoal are the most significant energy resources in Kenya and will continue to be in use in the foreseeable future. Firewood is mainly a rural fuel with a large population using it for cooking and heating. Due to decreased wood availability, some parts of the country are opting for agricultural residue and animal dung as energy for cooking (Kamfor, 2002). Since fuelwood is the major source of energy in rural areas of many developing countries, special efforts have to be made to improve cooking. One of the ways to do this is by replacing the traditional three stone stove with improved stoves (Karekezi *et al*, 1992). Due to the important role wood fuel energy plays in the day to day life of majority of Kenyans, more research needs to be done in order to plan how this important resource can continue to be utilized in a sustainable manner. Households are the most important category in wood energy consumption with an estimated consumption of 6.5 tonnes per household per year (Githiomi *et al,* 2012).

2.1.5 Wood fuel Supply and Demand Trend in Kenya

In the year 1980 biomass energy supplied 98% of Kenya's rural domestic sector's energy requirements and out of the 98% biomass energy, 93% was from wood fuel while 5% was from crop residues (O'Keefe *et al.,* 1984).In 1988 a study in Bungoma district of Kenya revealed that wood fuel was supplying only 54% of the energy required for cooking and heating annually while the rest 46% was from crop residues (Mugo, 1989) implying an increasing trend in the use of such materials. Increased use of crop residues for energy is an indication of increasing scarcity of fuel wood (Foley and Barnard, 1984).

Fuel wood scarcity may be physical and or economic (Dewees, 1995). Chambers and Leach (1987) found that where local markets for fuel wood exists trees were assets which could be cut and sold at short notice to meet urgent household financial needs and this contributed to economic fuel wood scarcities.

Suggestions of the root causes of the persistent and increasing fuel wood scarcity in Kenya include; inefficient end use utilization technologies (Mugo, 1989; 1997), limiting land tenure arrangements, small land sizes and land use factors especially the type of use land is put to and limited participation of by women in tree resource decision making and management (ICRAF, 1996;). Energy supply and demand vary by region, district, village and by household classes within a village. There is enormous diversity in the availability and costs of energy supplies, levels of consumption and mix of fuels employed, end users (cooking, water heating, space heating, lighting), technologies used, energy related preferences, and modes of behaviour (Leach and Gowen, 1987).

2.2 Types of Cooking Stoves

The traditional use of open wood fires for cooking whereby the cooking pot is centred on three stones or three bricks is predominant in developing countries. Change in technology has resulted to better improved stoves because of environmental concerns.

2.2.1 Traditional Three (3) Stone Stove

The traditional method of cooking is on a three-stone cooking fire. It is the cheapest stove to produce, requiring only three suitable stones of the same height on which a cooking pot can be balanced over a fire but then this cooking method has problems. In this method smoke is vented into the home instead of outdoors causing health problems.

According to the World Health Organization, 4.3 million people a year die prematurely from illness attributable to the household air pollution caused by the inefficient use of solid fuels (WHO, 2012). Fuel is wasted, as heat is allowed to escape into the open air. This requires the user to gather more fuel and may result in increased deforestation if wood is used for fuel. Only one cooking pot can be used at a time. Research carried out by Kamfor (2008) for Ministry of Energy, Kenya showed that traditional stoves consume up to 1.5 kg of fuel per person per day. The use of an open fire creates a risk of burns and scalds. This is particularly when the stove is used indoors, cramped conditions make adults and particularly children susceptible to falling or stepping into the fire and receiving burns.

2.3 Improved Stoves

The negative impacts caused by traditional three stone stoves can be reduced by using improved cook stoves, improved fuels (e.g. biogas, or kerosene instead of dung), and changes to user behavior (e.g. drying fuel wood before use and using a lid during cooking). Improved stoves are more efficient, meaning that the stove users spend less time gathering wood or other fuels, suffer less emphysema and other lung diseases prevalent in smoke-filled homes, while reducing deforestation and air pollution.

2.3.1 Fixed Firewood Stove:

Fixed stoves with a mud or cement brick construction are common in institutions. These are usually built up in situ, and can be made very cheaply using local materials. They work by directing hot gases from a fuelwood fire. They can be constructed to accommodate several cooking vessels and they are more permanent than the traditional stoves.

2.3.2 Improved Charcoal Wood Stove (Kenya Ceramic Jiko)

The Kenya Ceramic Jiko (KCJ) is one of the successful stove dissemination projects in Africa. The KCJ is made up of a metal cladding with a wide base and a ceramic liner. At least 25 per cent of the liner base is perforated with holes of 1.5 cm diameter to form the grate. The stove has two handles, three stands and an air opening. The standard model weighs about 6kg, which means it can be carried around easily (KENGO, 1991).

The stove is suitable for cooking and space heating. The KCJ helps to direct 25-40 per cent of the heat from the fire to the cooking pot. The traditional all metal stove that the ceramic Jiko replaces delivers only 10-20 per cent of the heat to the pot, whereas an open cooking fire yields efficiencies as low as 10 per cent (Kammen, 1995).

The KCJ stove was developed through a design process spearheaded by the Ministry of Energy. The stove easily found acceptance among rural stove producers who were initially offered free training and marketing support by KENGO, working with the ministries of Energy, Agriculture and Environment and Natural resources. KCJ is purchased mostly due to its ability to reduce cooking time, produce high quality meals, reduce charcoal consumption, minimize accidents, and ease of cleaning and maintenance. Its physical appearance is not a major concern or reason for a family to buy or not to buy the stove.

Although most producers and dealers of the stove have been men, many women in small rural areas have benefited immensely from the technology, significantly improving their standards of living through gains in time and income (Okello, 2005).Reductions in fuel use associated with the KCJ and other improved stoves have been examined in a number of countries. In Tanzania, annual fuel consumption for traditional charcoal stove was found to be around 1080 kg/year/household while for improved charcoal stove it was around 370kg/year/household and so annual charcoal saving is 710 kg/household which is equivalent to around 60 trees (TATEDO, 2005).

In Rwanda, the savings with improved charcoal stoves were even greater. There, consumption of charcoal dropped to 0.33 kg per person per day from 0.51 kg per person per day. This means that in a year a family could save about 394 kg of charcoal worth 6,310 Rwanda Francs (Ksh. 7,232) (Smith *et al*., 1994).

In Kenya charcoal use among a sample of families using the KCJ fell from 0.67 kg to 0.39 kg/person/day. This totals over 600 kg of charcoal/year for an average family, and a savings of over $US 64.7/year i.e. Ksh.5590 (Karekezi *et al,* 1997), Coelho et al, (2004). Other tests done in Kenya indicated an average decline in daily charcoal consumption from 0.7 kg to 0.4 kg per person with an improved stove Jones (1989), adding up to a total yearly saving of 613 kg per family (Smith *et al,* 1993). This would save on the money used for purchase of charcoal and thus help in improving the family living standards. It would also reduce demand for charcoal thus saving the forests trees, shrubs and herbs and thus promoting environment conservation.

According to Johnson *et al,* (2007) up to the equivalent of 10 tonnes of carbon dioxide may also be saved per household per year with an improved stove. This would reduce the GHG emission to the atmosphere and thus assist in mitigating against global warming and climate change

2.3.3 Improved Firewood Cooking Stove *(JikoKisasa)*

This is an improved type of stove which is more efficient in wood use. Firewood saving is mainly due to the fact that the fired clay liner ensures heat is retained in the stove over a long time. The fired ceramic liner provides the thermal insulation to minimize heat loss (GTZ/PSDA, 2007). The stove can be fixed in the kitchen and is commonly known as *maendeleo Jiko* or *JikoKisasa*) or *Kunimbili jiko*. According to a research study done in Tanzania, a household using three stones stove consumes around 2880 kg/year of firewood. According to the study, through the use of improved firewood stove consumption is reduced to 1728 kg/year/household, annual saving is around 1152 kg/household, equivalent to more than 20 trees/year) (TATEDO, 2004). The adoption of wood fuel saving technologies would go a long way in ensuring sustainable use of the forest resources as the fuelwood demand will decrease, it also reduces the time a woman spend in fetching firewood therefore releasing her to be involved in other productive activities.

The uptake of the fuelwood improved stove is estimated at 5%, yet majority of the rural people in Kenya use firewood as their main source of fuel (Muchiri, 2008). This has implication on sources of the biomass and ends up causing encroachment to forests in search of fuelwood impacting negatively on forest conservation. It also means that many people in the rural households especially women and children are exposed to indoor air pollution which is detrimental to their health thus the need for adoption of the energy saving technologies.

2.3.4 Fireless Cooker (Food Warmer)

This is an insulated basket, container or box that is specially designed to complete the cooking that has been done partially on conventional cooking technologies. It is also a food warmer for it keeps food hot for upto eight (8) hours after cooking (Owino, 2003).

Almost anything that can be boiled or steamed may be cooked in the fireless cooker with a great saving of the cook's time and labor as well as with an economy of fuel. There is a saving of work because the food does not need to be watched, it will neither burn nor boil over. Cooking utensils do not wear out so rapidly when used in a cooker as when used over a fire, and the kitchen is neither hot nor filled with odors. The cooking nature of the fireless cooker only allows for cooking of foodstuffs that do not need stirring during the cooking process (Taulo *et. al*., 2008).

A fireless cooker operate on the principle of thermal insulation where by food is brought to a boil then transferred into a carefully insulated basket or box to complete the cooking process using the trapped heat. According to Mugo and Poulstrup (2003) a fireless cooker reduces consumption of wood fuel by about 40%, thus by households adopting this technology in combination with the KCJ or *Kunimbili* stoves then a huge amount on wood fuel saving would be realized and this would tremendously reduce pressure on the diminishing wood fuel sources. This technology does not only assist in wood fuel saving but can also be used in saving other conventional forms of energy for cooking e.g. LPG or even electricity.

Table 2.3: Determinants of Stove/Fuel Choice

Social/Cultural	Economic	Technical
Family Size	Household income	Efficiency
Sex of Household head	Stove price	Safety
Age of Household head	Usage cost	Emissions
Education level	Fuel cost	Durability
Taste of food	Fuel availability	Speed of cooking
Cooking habits/customs		Portability
Fuel convenience		Aesthetic factor

Source: GIZ (2014).

2.4 Biogas Use in Kenya

Biogas is produced through anaerobic fermentation of biotic materials mainly animal dung, human faeces and crop residues and it is a mixture of methane, carbon (iv) oxide, Hydrogen and Hydrogen sulphide gases. Global experience shows that biogas technology is a simple and readily usable technology that does not require overtly sophisticated capacity to construct and manage. It has also been recognized as a simple, adaptable and locally acceptable technology for Africa (Taleghani, 2005).

Biogas energy though it appears quite insignificant, it can play a substantively prominent role in the energy supply in Kenya. Thus, the potential for biogas which is a product of animal dung, urine and other residues in transforming Kenya's rural economy has received less attention.

This is probably due to inadequate technical installations skills, unawareness and inadequate funding (COVARD, 2014). In Kenya, we have over 90% awareness of biogas use although the awareness has not been translated to adoption by most farmers. Enhanced user training is required and construction costs of biogas plants are still extremely high, hence unaffordable to most Kenyans (COVARD, 2014).

2.5 The Status of Solar Power Projects in Kenya

Kenya has abundant solar energy resources. Its daily average solar insolation is estimated to be about 4-6 kilowatt hours per square meter, which is considered one of the best for solar electric energy production in sub-Saharan Africa. In the year 2010 about 4.4% of rural households of Kenya had solar systems in their homes (ACTS, 2015). There has been a spectacular market growth of solar home systems in Kenya due to strong marketing efforts of the private sector with little (and often times no) support from the government (ACTS, 2015). Lack of Government commitment as well as various sociotechnical, management and economic barriers prevent photovoltaic technologies from being readily adopted (Karakaya, 2015). A study done by Mukami (2016) in Kiambu on solar energy technology adoption at household level revealed that lack of government support, lack of finances, insufficient technological expertise and availability of electricity as factors that affect adoption.

2.6 Adoption of Electric Energy and Challenges Faced by Rural Households in Kenya

Electrical energy for household use remains an important avenue of alleviating rural poverty especially in Developing Countries (Abdullah *et al.,* 2012). There is continued emphasis on increasing rural electricity accessibility to rural households globally whose adoption at household level is quite low (Kemmler, 2007).

There is unanimous consensus that households head income is a major factor that determines adoption of electricity in the residential sector (Abdullah *et al.*, 2012). Information, education, and social learning are also described as factors that determine rates of adoption electrical energy systems. Lack of information regarding the alternative energy systems and the associated benefits have been shown as a barrier towards adoption (Heltberg, 2003). Gender roles substantially influence decision making on energy at the household level. According to Clancy (1999), though women are the main end-users of energy they are limited in their involvement in planning and implementation levels of most of the projects in the energy sector. Often women are not in a position to make or influence decisions concerning energy use (Clancy, 1999). Distance of the household from the transformer is a determinant of electricity adoption among households (Andreas, 2006). Transformers act as electricity access points for rural households (REA, 2013).

2.7 Sustainability of Wood Energy Systems

At any given location there are many different sources of wood fuels. They can be collected from dead trees, pruning and other woody wastes collected from forests, woodlands and trees in farming lands. In many areas, a substantial amount of wood fuels originates from the biomass produced by land clearing operations when forests and woodlands are transformed into agricultural farms. Considerable amounts of wood fuels are also obtained from trees planted on marginal and farming lands through agroforestry schemes (FAO, 1996).

In places with intensive utilization of wood fuels, for example around large rural centres and in zones with a high concentration of commercial activities like brick-making, lime burning and sugar production, pressure on fuel wood supply sources can be heavy, with consequent deforestation and/or devegetation. Such areas face fuel wood and charcoal shortages and depletion of wood stocks.

Wood energy has great potential as a locally available and environmentally friendly (relative to fossil fuels) source of energy. However, in the short term the transition towards its increased utilization will be dominated by economic factors – more specifically, the cost-effectiveness of the technology used and the associated subsidies and incentives provided not only for wood energy but also for fossil fuels and other conventional energy sources.

2.9 Energy Content of Wood fuel Compared to other Sources

Liquefied Petroleum Gas (LPG) assumes the leading position among the most important energy carriers in developing countries. Depending on the type of wood fuel and cook stoves, between 2.5 kg of wood (charcoal) would be required to provide the same amount of effective cooking energy found in one kg of LPG. When considering the low efficiencies of the traditional kilns the amount of raw material required to replace one kg of LPG boosts up to around 30 kg of wood. With respect to energy density, combustion efficiency, heat transfer efficiency and heat control characteristics, LPG clearly assumes the leading position among the most important energy carriers in developing countries. (CRC-PREDAS, 2006)

2.10 Number of Trees Saved Annually by an Efficient Stove

Trees saved can be a difficult number to quantify since there are so many types and species of trees, but looking at Kenya as our baseline, the average weight of a tree across the three most prevalent species, is 195.5 kilograms (Paradigm project partners, 2008).

We are able to determine how many kilograms or pounds of wood are used in open fire cooking and compare that to the amount saved per efficient stove each year. Women are using up to 10 kilograms of wood to cook each day over inefficient open fires and are then using only 5 kilograms of wood on an efficient stove (Paradigm project partners, 2008). According to the Paradigm Project Partners, Kenya (2008), 7 trees are saved annually by a household which uses a 50% energy efficient stove based on the 195.5 average kilograms.

2.11 Measuring Wood Fuel and Charcoal

Much wood fuel is collected by the headload. Which could be measured either by volume or weight and an average for a particular district or country could be established. From surveys in Gambia and Tanzania by Openshaw, 1978, the average head load weighed about 26 kg whereas in Kenya it weighs 25 kg and in Sri Lanka 20 kg. However, the weight of wood depends upon the moisture content (M.C).If the wood is first allowed to dry out and become air dry then the moisture content may be around 12 to 15 percent, depending on the relative humidity of the atmosphere (Openshaw, 1978).

The average fuelwood load in sub-Saharan Africa is around 20 kg but loads of 38 kg have also been recorded (Rwelamira, 1999).The thermal properties of wood especially specific heat capacity is an essential physical property especially in the processes of drying, producing heat energy by combustion and other processes which include the transfer of heat through wood. Furthermore specific heat capacity does not depend on wood species or bulk density (Kristijan, 2014).

The volume of the firewood used per year varies from 0.30 m3 to 3.01 m3 depending on the size of the household, with an average volume of 1.56 m3 for an average household family size of seven persons (Agea *et al*, 2010) and the relative density of dry wood at moisture content 12% - 15% is 0.78 (Eric, 2008). Given that the density of water is 1000Kg/m3, then the density of dry wood at 12%-15% moisture content comes to 780 Kg/m3. When the average volume of 1.56$m^3$is multiplied with the density of 780, it gives a mass of 1217 Kg per year. This translates to about 4 Kg of wood per day for a family of seven members and so a bundle of 20 Kg would have been utilized in five (5) days.

2.12 Impediments to Accurate Wood fuel Information

According to FAO (2008), a number of reasons have been put forward regarding factors affecting accuracy of wood fuel information First high intensity surveys are necessary to collect accurate information since wood fuel production and consumption vary greatly across locations and at different times of the year. It is also evident that wood fuel is mostly collected for the collector's own use and not sold in specific locations, such as markets, shops or factories, which would facilitate collection of information. Because of the low price of wood fuel in most countries, the sector is of little economic importance and investment in collection of statistics is therefore considered of little value. Many countries do not have the financial and human resources required to collect wood fuel information especially since those countries that rely mostly on wood fuel are poor.

Despite its contribution to the national economy, wood energy is predominately produced and traded in the informal sector and thus escapes official statistics. The data provided by the different countries to FAO are often incomplete and/or erratic and do not accurately reflect reality. There is often poor coordination between institutions with an interest in the sector (e.g. government agencies dealing with agriculture, forestry, energy and rural development), and the benefit of information collection may be insufficient for any one agency. Information about wood fuel suffers from a lack of clear definitions, measurement conventions and conversion factors, which creates difficulties in comparing statistics across regions and over time. Because of widespread illegal logging, production may be under-declared and therefore the extent of wood residues available for energy use may be underestimated (FAO, 2008).

2.13 Adoption of Wood fuel Energy Conservation Technologies

According to Makame (2006), poor quality of the improved stoves, costs, information and education about the stoves were found to be the major factors for failure to adopt improved charcoal stoves in rural Zanzibar. Elvira (2008) reported that people base their decisions to buy a device on actual prices and do not have a good knowledge about the operational cost. Dupont

(1998) found that both US and Thailand ranked the price of a technology as an important determinant for the adoption of the energy efficient appliances.According to Bhattachary (2010) technology diffusion is limited by unavailability of information and they proposed that the best sources of information are the people who have already adopted the technology.

China is one of the countries that has had a successful improved stove program whereby early 90s it had disseminated 120 million improved stoves to the rural areas. According to Ramakrishna (1991) and Smith *et al* (1993) the success of China was attributed to the design and implementation of the program which included; Program concentrating efforts on areas of greatest need and selecting pilot counties with biomass fuel deficits. Direct contracts between the central government and the county bypassing much bureaucracy. This arrangement generated self- sustaining rural energy companies that manufactured, installed, and serviced stoves and other energy technologies.

Local rural energy offices were in-charge of technical training, service, implementation, and monitoring for the programs. Chinese improved stoves were not only suitable for fuel savings but also, designed for convenience and attractiveness, highlighting the lessons learned from problems in early programs that stressed fuel savings. Stove adopters paid the full cost of materials and labor. The government only helped producers through stove construction, training, administration, and promotion. Stoves that are mass-produced by a group of artisans or a small factory will be disseminated far more quickly than custom-built models whose construction and installation may depend on the availability of trained technicians or installers (Smith, *et al.* 1993).

A study carried out by Evans (1987) found out that stoves which are primarily designed to reduce the quantities of fuel-wood used can only be expected to be successful in areas where there is an acute fuel shortage, namely rural areas with an ecologically degraded environment and for poor households in peri-rural areas where fuel costs are high.Women spend 4 hours every day cooking when using traditional stoves. They can save 1 hour and 10 minutes when using a clean cook stove (Global Alliance, 2011)

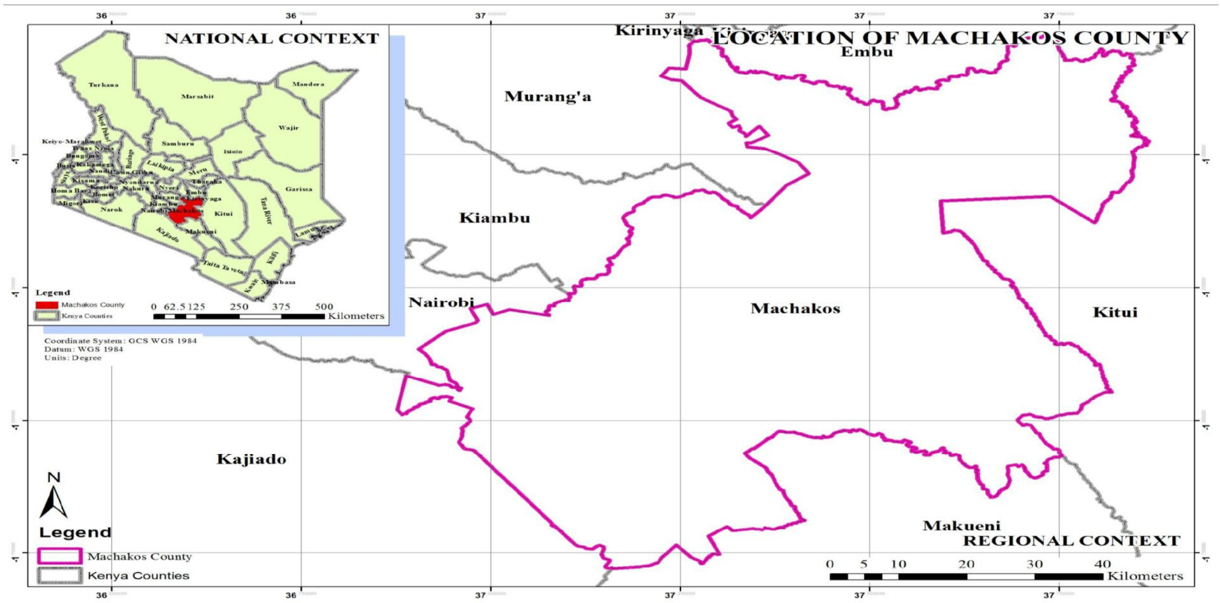
CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Study Sites (Locale)

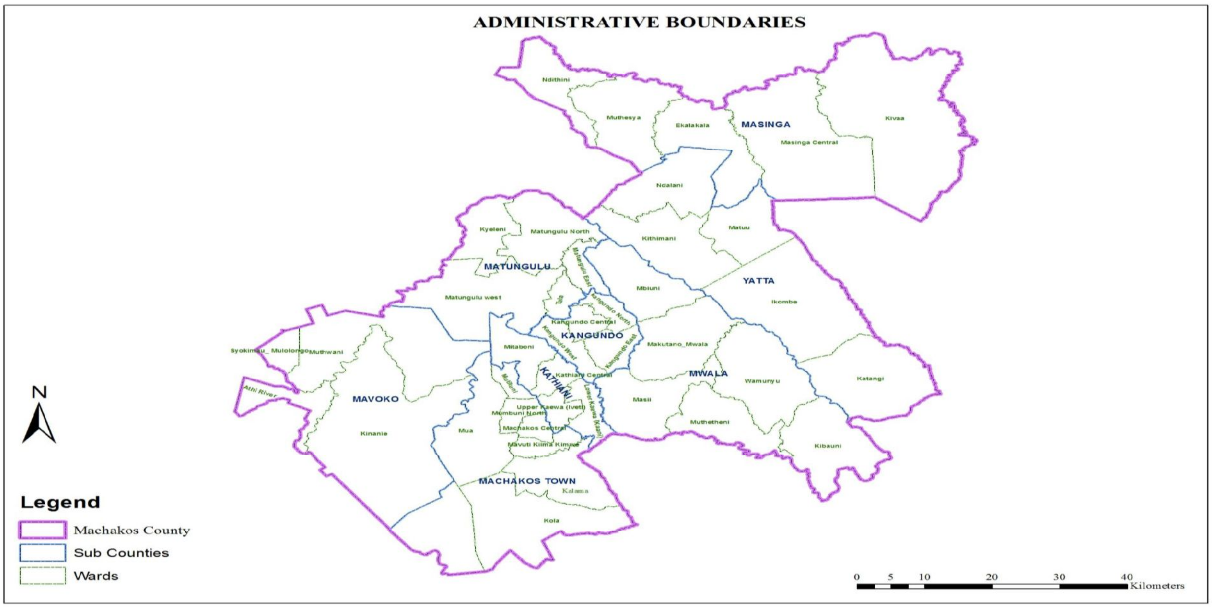
Mwala sub location is located 1° 41' 38'' S, 1° 6' 25'' S and 37° 0' 0'' E, 37° 57' 0''E with minimal elevation 864m and maximum elevation 2141m. Kibauni sub location is located 1° 41' 38'' S, 1° 6' 25'' S and 37° 0' 0'' E, 37° 51' 0''

Figure 3.1: Map of Machakos County and Neighboring Counties



Machakos County Integrated Development Plan, 2018-2022

Figure 3.2: Map of Machakos County and Sub-Counties



Source: Machakos County Spatial Database 2014

Figure 3.3: Map of Mwala Sub-County Showing Mwala and Kibauni sub location

Source: Hybrid Google Map of Mwala

3.2 Climatic conditions in Mwala Sub- County

Mwala Sub county receives bimodal rainfall with short rains in October and December while the long rains from March to May. The rainfall range is between 500mm and 1250mm, which is unevenly distributed and unreliable. The altitude mainly influences rainfall distribution in the county. The high areas such as Kanzalu hill and Kibauni hill receive an average rainfall of 1000mm while the lowland areas receive about 500mm. Temperatures vary between 18˚C and 29˚C throughout the year. The dry spells mainly occur from January to March and August to October (Machakos CIDP, 2018).

3.3 Forest Types and Sizes in Mwala Sub- County

The total forest cover in the County is 3.37% while the national cover is 6.99%. The Kenyan Constitution, Vision 2030 and international standards require at least 10% forest cover for sustainable development. Kibauni Hill forest (1619 Ha) and Mango forest Hill (45 Ha) are examples of state forests which contribute a lot in provision of firewood and charcoal for residents but most residents in Mwala subcounty depend on sparse vegetation for firewood. The main forest products in the County are firewood, charcoal, poles, posts and timber for building and construction. Others include wood carvings in Wamunyu and apiculture for domestic and commercial purpose (Machakos CIDP, 2014).

3.4 Hydrology and drainage

The study area is drained by two seasonal rivers: Athi River and Miu. The mean annual rainfall of the area is 602 mm, distributed over a long (March-May) and a short (October-December) rain season, separated by a distinct dry season. The rains on the southern and eastern slopes of the mountains tend to be prolonged. The average monthly maximum temperature varies between 22.2°C and 27.3°C and the minimum temperature varies between 11.1°C and 15.2°C (Ellenkamp,2004).

3.5 Research Design

For the purpose of this study, survey methodology and observation were used.Survey is useful in describing the characteristics of a large population can provide broad capability, which ensures a more accurate sample to gather targeted results in which to draw conclusions and make important decision.

3.6 Target Population

The research targeted households in, Mwala and Kibauni sub-locations with , 522 and 327 households, respectively (Machakos CIDP, (2014) The sub-locations were because wood fuel is extensively used for household purposes, commercial purposes and baking of bricks, a major material for construction of houses in the area. These activities enhances deforestation and soil degradation.

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3.7 Sample Size and Sampling Technique.

According to Amugune (2014), a sample size can be chosen from a population with arange of precision from 5%, 7% and 10%. For the purpose of cost effectiveness, a precision of 10% was chosen. By applying a simplified formula for proportions by Yamane (1967) shown below sample sizes for each sub-location will be calculated.

$$n = \frac{N}{1 + N(e)^2}$$

Where n= sample size. N= Population/Households and e= level of precision. The table 3.1 below shows sample sizes in each sublocation.

Table 3.1: Sample sizes in Kibauni and Mwala Sublocations

Sub- Location	No. of Households	Sample size
Mwala	522	83
Kibauni	327	77
TOTAL	**160**	

Source: KBS, 1999

The sample size was therefore 160. Purposive sampling method was used and it on households at sub-locational level exclusively using improved stoves and traditional three stone stove, fuel wood only and those using both fuel wood and charcoal. Selection of particular respondent was done randomly because all households have an equal chance of selection, hence avoiding bias.

3.8 Data Collection Instruments

Data collection was done using questionnaires and interview schedules from January to March 2017. Interview schedules were used for respondents who were not literate. Questionnaire is an ideal instrument to gather descriptive information from a large sample in a fairly short time (Kothari, 2004). The study collected data from heads of the households (male or female). Questionnaires were used to collect data on information pertinent to wood fuel utilization behaviors in the homestead and respondents perception on the need to conserve the environment.

The questionnaire was semi-structured and was administered by means of personal interviews in order to encourage the respondents to participate and to allow probes, clarification by the interviewer as observed by Peril *et al* (1982). Open ended questions were used to allow the respondents to give their own opinions. Closed ended questions were presented with a series of choices and allowed the respondents to choose one answer. The questionnaire was used to gather information on educational level, gender status, number of children, income level, types of energy saving devices in use, source of fuel wood and other information important for the study.

Secondary data was sought from annual reports of relevant ministries, NEMA, and books relevant to the area of research. A total of 160 questionnaires were administered, 83 for Mwala sub-location and 77 for Kibauni Sub-Location.

3.9 Instrument Validity and Reliability.

The semi structured questionnaire was pretested in order to gauge its reliability in gathering the required data. A sample of 20 households was selected randomly outside the area of the study and involved in filling the questionnaire. The number 20 was chosen for pre-test because according to Kathuri and Pals (1993) it is the smallest number that can yield meaningful results on data analysis in a survey research. Corrections were made on the questionnaire/interview schedule before being administered to the households involved in the study.

3.10 Data Collection Procedure

The research Assistants were first trained to obtain vital skills on administration of questionnaires, interview schedules and how to interact with the respondents. Consent was then sought from the respondents, research procedure explained and confidentiality assured. The administration of the research instruments was done.

3.11 Data Analysis and Presentation

Data cleaning was done to remove minor errors that occurred during the collection process. Data was analyzed using the Statistical package for social science (SPSS) computer software version 23.0. Data analysis consisted of both descriptive and analytical components with a variety of statistical tools to describe the study population. SPSS was preferred because it is easy to use and accepts a wide range of data processing to give desired values and is also readily available as compared to other statistical packages. Descriptive statistics was used to analyze the characteristics of the population studied.

According to Trochim (2006) descriptive statistics are used to describe the basic features of the data in a study providing simple summaries about the sample and the measures. Means, standard deviation, Frequency tables, bar charts and percentages were used. These were used to describe demographic data such as gender, family size, level of training etc. According to Smith (2011) inferential statistics are used to make inferential statements about a population. It makes use of random sampling techniques to make sure the sample is representative. Anova Test (significance level of 0.05) was used to test whether there was any significant difference in the type of stove used, level of adoption of wood fuel saving measures in relation to amount of wood used in the two Sub-locations. Z Test was used to test the proportional difference of samples in the two sublocations.

3.12 Ethical Consideration

Mugenda (2003) affirms that ethical consideration is important in ensuring a professional and a non-intrusive in accomplishing a research objective. For this study, permission to carry out the study from relevant administrative authorities in the study area was sought. The researcher assured confidentiality to the respondents and confirmed that the study is for the purposes of accomplishing academic goals only.

CHAPTER FOUR

4.0 RESULTS

4.1 Gender of the Respondent.

In Mwala Sub-location, the male respondents were 10 representing 12% and the female respondents were 73 representing 88% (Table 4.1). This was an indication that women in Mwala Sublocation were the ones majorly concerned with the kitchen affairs and collection of wood fuel but men are out for work being sole bread earners.

In Kibauni, the male respondents were 13 representing 16% and the female respondents were 64 representing 83% (Table 4.1).Just like Mwala women in Kibauni were the majority respondents. On testing for proportional difference of gender in the two study areas (Z Test at 5% significant level), there was no significant difference for males, Z= -0.3283, p= 0.7414. There was also no significant difference for females, Z= 0.7997, p=0.4237

Table 4.1: Gender of the Respondent

	Gender	frequency(f)	%
MWALA	Male	10	12
	Female	73	88
KIBAUNI			
	Male	13	16.4
	Female	64	83.6

4.2 Family Size of the Households in Mwala and Kibauni Sublocations

In Mwala sub-location, 46 households had a family size of 6 representing about 55%, 16 households had a family size of 5 representing 19%, 10 households had 4 representing a 12%, 4 households had 8 representing 5%, 3 households had 3 members representing 4% , 3 households had 2 members 4%, 1 household had 7 members representing about 1% and there was no family with a family size of 1 member. The majority of the families had six family members and the mean family size was six (6) (Table 4.2).

In Kibauni, sub location31 households had a family size of 6 members 40%, 17 households had a family size of 5 representing 22%, 11 households had 4 representing 14%, 9 households had 3 members representing 12%, 6 households had 7 representing 8%, 3 households had 2 members which 4% and no household had a family size of 1 member. The majority of the households had a family size of six (6) and the mean family size was six (6) just like in Mwala sublocation (Table 4.3). .

Table 4.2: Family Size of households in Mwala sub location

	family size	**Frequency**	**%**	**Mean**	**N**	**standard deviation**
	1	0	0			
	2	3	3.6			
	3	3	3.6			
	4	10	12			
MWALA	5	16	19.3	5.42	83	.929
	6	46	55.4			
	7	1	1.2			
	8	4	4.8			

Table 4.3: Family Size of households in Kibauni sub location

	family size	**frequency**	**%**	**Mean**	**N**	**std dev.**
	1	0	0			
	2	3	3.8			
	3	9	11.7			
	4	11	14.3			
KIBAUNI	5	17	22.1	5.06	77	1.343
	6	31	40.3			
	7	6	7.8			

4.3 Common Stoves used by Households

Results of the highly utilized stove in Mwala Sublocation showed that 77 households representing about 93% were using traditional three stone stove, 3 households representing about 4% used fixed brick stove, 2 households representing about 2% used portable clay lined stove, 1 household representing about 1% used ecozoom stove (jikokoa) and no household used the portable full metallic stove (Table 4.4).

In Kibauni 74 households representing 96% were using traditional three stone stove, 1 household representing about 1% used fixed brick stove, 2 households representing about 3% used portable clay lined stove and none of the households used ecozoom (jikokoa) and portable full metallic stoves (Table 4.4).

The results of the common stove in the two sublocations were exposed to a proportional test which showed that there was no significant difference in the usage of all the stoves in both Mwala and Kibauni sub-locations except portable full metallic stove (Z= 0/0, p=0). The traditional three stone stove (Z= -0.8036, p=0.4179), fixed brick stove, fixed brick stove (Z= 0.9374, p= 0.347), portable clay lined (Z= -0.076, p= 0.936), ecozoom (Z= 0.9662, p= 0.33)

Table 4.4: Common stove used by households on daily basis

	common stove	**frequency (f)**	**%**
MWALA	Traditional 3 stone stove	77	92.8
	Fixed brick stove	3	3.6
	Portable clay lined	2	2.4
	Ecozoom/Jikokoa	1	1.2
	Portable full metallic	0	0
	Traditional 3 stone stove	74	96
	Fixed brick stove	1	1.29
KIBAUNI	Portable clay lined	2	2.6
	Ecozoom/Jikokoa	0	0
	Portable full metallic	0	0

4.4 Factors Determining the Type of Stove Chosen by the Households

In Mwala sublocation, 70 households representing 84% reported economic factors as determinant in choosing the type of stove chosen, 12 households representing 15% relied on cultural factors and 1 household representing 1% reported technical factors for choosing a stove (Table 4.5).This was a clear indication that most of the households in Mwala experience economic hardships, hence the economic hardships determined stove choice, 14% of the households associated the use of stoves to cultural reasons, meaning that the Traditional 3 stone cookers to them were more cultural and improved stoves were associated with the western culture.

In Kibauni 50 households representing 65% were controlled by economic factors in choosing a stove, 23 households representing 30% were guided by cultural factors and 3 households representing 4% based on technical factors (Table 4.5). A test of proportional difference showed that there was no significant difference for cultural and technical factors in the two sublocations. The values were Z= -0.9982, p=0.31732 and Z= -0.1324, p= 0.8966 for cultural and technical factors respectively. However there was significant difference in economic factors for the two areas, Z= 2.4608, p= 0.0139.

Table 4.5: Factors determining type of stove chosen by the households

	Factor	Frequency	%
MWALA	Economic factors	70	84.3
	Cultural factors	12	15.5
	Technical factors	1	1.2
KIBAUNI	Economic factors	50	64.9
	Cultural factors	23	29.9
	Technical factors	3	3.9

4.5 Common form of WoodFuel Used by the Households

In Mwala Sub-Location, 81 households representing 98%, used firewood and 2 households representing 2% used charcoal as their daily fuel for their cooking and heating purposes (Table 4.6).

The results of Kibauni show that 73 households representing 95% used firewood compared to 4 households representing 5% who were using charcoal (Table 4.6). This compares well with the results of Mwala where firewood was the dominant fuel type used by the majority of the respondents. The high consumption of firewood can lead to massive cutting of trees and in turn environmental destruction if not controlled.

A significant test of proportional difference of both firewood and charcoal in the two sublocations showed that there was no significant difference in the two sublocations. For firewood Z=0.0629, p=0.9522 and for charcoal Z= -0.0468, p=0.9601.

Table 4.6: Common form of wood fuel used by the households

	common fuel	**frequency (f)**	**%**
MWALA	Firewood Charcoal	81	97.6
		2	2.4
KIBAUNI	Firewood Charcoal	73	94.8
		4	5.2

4.6 Level of Adoption of Energy Saving Measures by the Households

The energy saving measures researched included rationing of wood, splitting wood and putting off fire after use. The manner of utilization of the available wood fuel may have an impact in wood fuel exploitation, fuel cost and distance and length of time used during the collection of wood fuel.

4.6.1 The Practice of Wood Fuel Rationing by the Households

In Mwala 54 households representing 65% were not rationing their wood during their cooking process while 29 households representing about 35% were doing rationing (Table 4.7).

In Kibauni 65 households representing about 84% were not rationing wood while 12 households representing about 16% were doing rationing (Table 4.7). A proportional test of proportions showed a significant difference in rationing of wood (Z=2.1605, p= 0.031) and also a significant difference in non-rationing of wood (Z= -2.4419, p= 0.014).

Table 4.7: The Practice of Wood fuel rationing by the households

	Response	frequency (f)	%
MWALA	Rationing	29	34.9
	No rationing	54	65.1
KIBAUNI	Rationing		
	No rationing	12	15.6
		65	84.4

4.6.2 The Practice of Splitting of Wood fuel by Households

In Mwala sub location 58 households representing about 70% were not splitting their wood while 25 households representing about 30% were splitting (Table 4.8).

In Kibauni 68 households representing about 88% were not splitting their firewood and only 9 households representing about 12% were splitting their firewood (Table 4.8). A proportional test revealed significant difference for those who did not split wood in the two study areas (Z= 2.5772, p= 0.0099) but no significant difference in the ones who did splitting (Z= 1.085, p= 0.28014).

Table 4.8: The practice of Splitting wood fuel by households

	Response	frequency (f)	%
MWALA	Splitting	25	30.1
	No splitting	58	69.9
KIBAUNI	Splitting	9	11.7
	No splitting	68	88.3

4.6.3: The Practice of Putting Off Fire after Use

The results of Mwala indicated that 55 households representing about 66% were not putting off their fire after cooking compared to 28 households representing about 34% who were putting off their fire after use (Table 4.9).

Households in Kibauni sub location were also interviewed whereby 62 households representing about 81% were not putting off their fire after cooking compared to 15 households representing 19% who were putting off their fire after cooking (Table 4.9). Majority of households in both sublocations were not putting off fire which is an implication of wood fuel wastage. Test of proportional difference revealed that there was no significant difference in putting off fire (Z= 1.036, p= 0.298) and not putting off fire (Z= - 1.7856, p= 0.073) in the two sublocations.

Table 4.9: The practice of Putting off fire after use

	Response	frequency (f)	%
MWALA	Putting off fire	28	33.7
	No putting off fire	55	66.3
KIBAUNI	Putting off fire	15	19.4
	No putting off fire	62	80.6

4.7Anova Test on the Relationship between Independent and Dependent Variables

One way Anova test was used to test the relationship between the type of stove and the number of days taken to utilize a bundle of 20 kg of dry wood at 12%-15% moisture content. The study found a significant relationship between the type of stove and the number of days taken to consume one 20kg bundle of wood (df=1 and 158, F=8.187, p=0.005).

The research also found a significant relationship between rationing of wood fuel and the number of days taken to consume a bundle of 20kg wood (df=1 and 158, F=462.898, p=0.00). Also there was a significant relationship between Splitting of wood and the number of days taken to consume a bundle of 20kg of dry wood (df= 1 and 158, F= 83.2, p=0.00).The study also found a significant relationship between putting off fire after use and the number of days taken to consume a bundle of 20kg wood (df=3 and 156, F=57.292, p=0.00).

4.8: Training of Respondents on Energy Saving Measures

The aspect of training after interviewing the respondents showed that in Mwala 51 respondents representing 65 % of the respondents were not trained on sustainable wood fuel utilization skills while 32 respondents representing 35% of the respondents representing were trained (Table 4.10. This is an indication that most of the people have little or no knowledge in ensuring sustainable wood fuel usage.In Kibauni 71 respondents representing 84% of the respondents were not trained on sustainable wood fuel utilization techniques while only 6 respondents representing 16% were trained (Table 4.10). A significance Test of proportional difference showed that there was no significant difference in the ones trained whereby Z= 1.464, p= 0.1443. The same test showed a significant difference in the ones not trained, Z= -4.1079, p=0 for the two areas of study.

Table 4.10: Training of Respondents on energy saving measures

	Response	**frequency (f)**	**%**
MWALA	Trained	32	34.9
	Not Trained	51	65.1
KIBAUNI	Trained	6	15.6
	Not Trained	71	84.4

4.9: Wood fuel Supply to the Households

In Mwala sub location 71 households representing about 85% were of the view that wood fuel supply was scarce whereas 12 households representing about 15% reported high supply of wood fuel (Table 4.11).

In Kibauni sub location 67 households representing 87% were of the view that wood supply was scarce while 10 households representing 13% reported high supply of wood fuel (Table 4.11). The proportional test done showed no significant difference for those who reported scarce Z $-0.256,$ 0.795 or high supply of wood (Z=0.1018,p= 0.9203) in Mwala and Kibauni sub locations.

Table 4.11: Wood fuel supply to the households

	Response	frequency (f)	%
MWALA	Scarce	71	85.5
	High supply	12	14.5
	Scarce	67	87.0
KIBAUNI	High supply	10	13.0

4.10 Number of Days Taken to Utilize One Bundle of 20 Kg of dry wood

In Mwala 57 households representing about 69% utilized the bundle in 2 days, 15 households representing 18% utilized in 3 days, 8 households representing 9% in 4 days and 3 households representing 3% utilized in 5 days and the mean number of days taken to utilize the bundle of 20Kg was two (2) days (Table 4.12).

The corresponding results for Kibauni indicate that 65 households representing 84% utilized a bundle of wood in 2 days, 9 households representing 12% representing utilized in 3 days and 3 households representing 3% utilized a bundle in 4 days and the mean of the days taken was two (2) days (Table 4.12). The mean usage for the two sublocations was about two (2) days.

Table 4.12: Number of days taken to utilize one bundle of 20 Kg of dry wood

	Days	Frequency	%	mean	standard deviation
MWALA	1	0	0		
	2	57	68.7		
	3	15	18.4		
	4	8	9.4	2.12	.913
	5	3	3.3		
	6	0	0		
KIBAUNI	1	0	0		
	2	65	84.4		
	3	9	12.6	2.31	.583
	4	0	0		
	5	0	0		
	6	0	0		

4.11 Alternative Energy Sources used to Complement Woodfuel

The results of Mwala Sublocation showed that none of the respondents i.e. (0%) had biogas, 16 households representing 19% had solar power, 11 households representing 13% had electricity and 56 households representing 67% did not have any of these energy sources (Table 4.13). Considering Kibauni sublocation, none of the respondents had biogas (0%), 23 households representing 28% had solar power, 7 households representing 8% had electricity and 47 households representing 57% did not have any of these alternative energy sources (Table 4.13) . Exposing the results to Z Test, there was significant difference in the number of households utilizing biogas with Z=Nan, p=0. But there was no significant difference in the number of households utilizing solar power (Z= -1.559, p= 0.119), no significant difference in the use of electricity (Z= 0.8325, p= 0.406) and no significant difference in the number of households who utilized none of the energy sources (Z= 0.8487, p= 0.3953) in the two sample sublocations.

Table 4.13:Alternative Energy sources used by the Households

	Energy	**Frequency**	**%**
MWALA	Biogas	0	0
	Solar	16	19
	Electricity	11	13
	None	56	67
KIBAUNI	Biogas	0	0
	Solar	23	28
	Electricity	7	8
	None	47	57

4.12 Challenges faced in adopting Biogas as an alternative energy source

It was found from the research that in Mwala Sublocation, 13 households representing about 16% expressed lack of information on biogas operation and existence as a challenge, 28 households representing about 34% mentioned poor acceptance in using biogas, 26 households representing 31% chose lack of technical knowledge, 4 households representing about 5% complained lack of government support in implementation and 12 households representing about 15% revealed cost of installation and maintenance as a challenge. In Mwala majority of the respondents chose poor acceptance on the use of biogas by residents as the major factor. In Kibauni sublocation 9 households representing about 12% revealed lack of information as a factor, 24 households representing 31% mentioned poor acceptance in the use of biogas, 31 households representing 40% chose lack of technical knowledge in installation and use of biogas as a factor, 7 households representing 9% mentioned lack of Government support in implementation of biogas industry and 6 households representing about 8% chose cost of materials as a challenge. In Kibauni Sublocation unlike in Mwala, lack of technical knowledge in the use of biogas was rated by majority of the respondents as the major challenge. The results from the two sample sites were exposed to Z Test at significant level P<0.05 and it was found that there was no significant difference for the challenge of lack of information (Z=0.729, p=0.465), no significant difference for poor acceptance (Z=0.346,p=0.726), no significant difference in lack of technical knowledge (Z= -1.179, p=0.238), no significant difference in lack of Government support (Z= -1.067, p=0.286) and no significant difference in cost of installation (Z=1.333, p=0.183).

Table 4.14: Challenges in adopting Biogas as an alternative energy source

	Energy	Challenges	frequency (f)	%
MWALA	Biogas	Lack of information	13	15.6
		Poor acceptance	28	33.7
		Lack of Technical knowledge	26	31.3
		Lack of Government support	4	4.8
		Cost	12	14.5
KIBAUNI		Lack of information	9	11.6
		Poor acceptance	24	31.2
		Lack of Technical knowledge	31	40.3
		Lack of Government support	7	9.1
		Cost	6	7.8

4.13 Challenges faced in adopting solar power as an alternative energy source

In Mwala sublocation the variability factor of solar energy, which means availableness of solar energy came up. 21 households representing 25% chose variability as a challenge and 62 households representing about 75% mentioned high initial cost of installation. Considering

Kibauni,14 households representing about 18% chose variability as a challenge compared to 63 households representing about 82% who chose high initial cost of installation. So in both sublocations high initial cost came up as the major challenge in installation of solar power by the households. When the results of Mwala and Kibauni were compared, there was no significant difference for the challenge of variability (Z=1.088, p=0.225) and also no significant difference in the response for high initial cost of installation (Z= -1.088, p=0.275).

Table 4.15: Challenges in adopting solar power as an alternative energy source

	Energy	**Challenges**	**frequency (f)**	**%**
MWALA	Electricity	Variability	21	25.3
		High initial cost	62	74.6
KIBAUNI		Variability	14	18.1
		High initial cost	63	81.8

4.14 Challenges faced in adopting electricity as an alternative energy source

When the respondents in Mwala sublocation were questioned regarding the barriers hindering the use of electricity, 54 households representing 65% mentioned distance from the transformer as a major challenge, 20 households representing 24% mentioned wiring costs and 9 households representing about 11% chose unscheduled power cuts as a challenge. In Kibauni 52 households representing about 68% chose distance from the transformer, 17 households representing 22% mentioned wiring costs and 8 households representing 10% chose unscheduled power cuts as a challenge. In the two study areas distance from the transformer proved to be the major challenge hindering adoption of electricity by the residents. A Z Test of the results showed that there was no significant difference in the challenge of distance from the transformer (Z= -0.3304, p= 0.741), no significant difference for wiring costs (Z=0.302,p=0.764) and no significant difference in the challenge for unscheduled power cuts (Z=0.093, p=0.928).

Table 4.16: Challenges in adopting Electricity as an alternative energy source

	Energy	Challenges	frequency (f)	%
MWALA	Electricit	Distance from the Transformer	54	65
		Wiring costs	20	24
		Unscheduled power cuts	9	11
KIBAUNI		Distance from the Transformer	52	68
		Wiring costs	17	22
		Unscheduled power cuts	8	10

4.15 Advantages of adopting biogas as an alternative energy source over wood fuel

Biogas energy being renewable energy source is preferred over most of the non-renewable energy sources used today worldwide. In Mwala 26 households representing 31% mentioned availability of materials required as an advantage, 30 households representing 36% agreed that biogas use is environmentally sustainable and 27 households representing about 33% said biogas promotes good health. In Kibauni sublocation 19 households representing about 25% gave availability of materials as an advantage, 38 households representing 49% concurred that biogas is environmentally sustainable and 20 households representing about 26% said it promotes good health. According to the responses got from the two study sites environmental sustainability was the major advantage of adopting biogas energy. The results showed no significant difference for the advantage of availability of materials for making the biogas (Z=0.934, p=0.352), no significant difference in environmental sustainability (Z= -1.684, p=0.09) and no significant difference in promotion of good health (Z=0.9097, p=0.362) as advantages in the two study areas

Table 4.17: Advantages of adopting Biogas as alternative energy source over wood fuel

	Energy	Challenges	frequency (f)	%
MWALA	Biogas	Availability of materials	26	31.3
		Environmentally sustainable	30	36.1
		Promotes good health	2719	32.5
KIBAUNI		Availability of materials	38	24.6
		Environmentally sustainable	20	49.4
		Promotes good health		25.9

4.16 Advantages of adopting solar power as an alternative energy source over wood fuel

In Mwala 45 households representing 54% mentioned that solar power has no negative effects on climate change, 32 households representing about 39% concurred that solar power is reliable and 6 households representing 7% said that it offers energy security.In Kibauni sublocation 34 households representing 44% mentioned it has no negative effects on climate change, 33 households representing about 43% said it is reliable and 10 households representing about 13% said it provides energy security. In the two study sites the advantages of no negative effect on climate change and reliability were dominant. A proportional Test showed no significant difference in the response of biogas having no negative effects on climate change (Z=1.272, p=0.204), no significant difference in advantage of reliability (Z= -0.553, p=0.582) and no significant difference in the factor of energy security (Z= -1.213, p=0.226) in the two study areas.

Table 4.18: Advantages of adopting Solar power as alternative energy source over wood fuel

	Energy	Advantages	frequency (f)	%
MWALA	Solar power	No effect on climate change	45	54.2
		Reliable	32	38.5
		Energy security	6	7.2
		No effect on climate change	34	44.2
		Reliable	33	42.8
KIBAUNI		Energy security	10	12.9

4.17 Advantages of adopting electricity as an alternative energy source over wood fuel

The respondents in the two study areas were questioned to give their perception on the advantages they would get by adopting electricity. In Mwala 23 households representing about 28% said electricity boosts business, 32 households representing about 39% mentioned clean and healthy lighting and 28 households representing about 34% mentioned improvement of education. In Kibauni Sublocation 31 households representing 40% gave the opinion of boosting business, 27 households representing 35% said it provides clean and healthy lighting and 19 households representing about 25% mentioned improvement in education. So in Mwala clean and healthy lighting were the major advantages as opposed to Kibauni where business diversification was the major advantage according to the household responses. A proportional Test showed no significant difference in the advantage of business diversification (Z= -1.677, p=0.09), no significant difference in the clean and healthy lighting factor (Z=0.4571, p=0.645) and no significant difference in improvement of education as an advantage of electricity in the two areas.

Table 4.19: Advantages of adopting Electricity as alternative energy source over wood fuel

	Energy	**Advantages**	**frequency (f)**	**%**
MWALA	Electricity	Business diversification	23	27.7
		Clean and health lighting	32	38.5
		Improve Education	28	33.7
		Business diversification	31	40.2
KIBAUNI		Clean and health lighting	27	35.1
		Improve Education	19	24.6

CHAPTER FIVE

5.1 DISCUSSION

5.2 Introduction

This chapter comprises of the implications of the results obtained from the study. It also considers similar research findings from other researchers and how they relate to the results obtained.

5.3 Common Stoves used by Households on daily basis

The traditional three stone stoves was the most popular type of stove in the study areas Mwala having about 93% of the households and Kibauni 96% households using it on daily basis.(Table 4.4).The high percentage of users closely relates with results of a research done in Njoro by Florence Wanjala *et al* (2015) where 71% of households used the traditional stove. The stove was preferred because of its low cost, ability to warm the whole house, ability to accommodate many people to sit around it for warmth and flexibility in adjusting the size to accommodate different sizes of cooking vessels.

The above reasons are consistent with FAO (2014) that the three stone stove enhances space warming through radiating heat and the family could sit around the fire place during the cold season and is also of low cost. On the other hand the traditional three stone stoves are very wasteful in terms wood fuel usage since it has low energy efficiency as compared to the other improved stoves. Continued use of this traditional stove will endanger tree cover hence unsustainable utilization of wood fuel in the long run. In the study area therefore there is wastage of biomass and energy since this stove is energy inefficient hence wood fuel is utilized unsustainably. As reported by Venkataraman *et al*. 2010), biomass fuels burned in traditional ways contribute to a buildup of greenhouse gases (GHGs), as well as other climate forcers, including black carbon (BC), in the atmosphere (Ramanathan and Carmichael, 2008).

The fixed brick stove was the other stove used by the households although the percentage of the users was very low, about 4% in Mwala and 1% in Kibauni sublocations (Table 4.4). This is a type of improved stove which uses firewood and is currently used by institutions because it can be constructed to accommodate several cooking vessels of different sizes and its ability to conserve/utilize less fuel than the traditional stove. Households are currently embracing the use of this stove since it is constructed using local materials like bricks which are readily available. The cost involved in the use of cement and metal bars required in the construction in addition to technical knowhow are possible reasons that made the stove not popular in the study areas.`

The portable clay lined stove also referred to as the Kenya ceramic stove was also used by few households, about 2% in Mwala and about 3% in Kibauni (Table 4.4).This is another type of improved stove that uses charcoal and it costs about Ksh.400. It has a thick clay lining inside that acts as heat insulator, preventing heat loss to the outside but concentrating all the heat to the cooking vessel. The low usage of this stove was presumably due to the fact that it is not convenient since uses charcoal which needs to be bought, not suitable for big cooking pots and is suitable for small families. For most households it was used to complement the traditional three stone stoves.

The ecozoom stove also referred to as jikokoa is a modern improved stove that realized low usage in Mwala, a percentage of 1% and in Kibauni there was no single household using it (Table 4.4). It is very efficient in terms of energy conservation and it can use both charcoal and wood. This stove being a new technology was probably not known by many households. Again the stove is very expensive for most rural households one stove costing between Ksh. 4000 to Ksh. 5000.

The portable full metallic stove was not used by any of the households sampled in Mwala and Kibauni (Table 4.4). Being the oldest of the portable stoves that use charcoal, it is being phased out because unlike the portable clay lined stove, it radiates a lot of heat, does not last long and has no mechanism of heat loss prevention.

There was also significant relationship between the type of stove and the number of days taken to consume one 20kg bundle of dry wood (df=1 and 158, F=8.187, p=0.005). This means that the traditional stove consumed a bundle of wood in fewer days than improved stove because of its lower energy efficiency which led to much usage of fuel. Therefore continued use of this traditional stove without corresponding reaforestation programme and without embracing energy conservation measures during cooking process will be detrimental to the environment.

5.4 Level of Adoption of Energy Saving Measures

5.4.1 The Practice of Rationing of WoodFuel

Wood rationing as a means of controlling the amount of wood fuel consumed was not practiced by majority of the respondents. 84% in Kibauni and 65% in Mwala did not practice wood rationing (Table 4.7).Non rationing of wood fuel leads to fuel wastage and this endangers our little forest cover given that much of land has been cleared for purpose of food production. There is therefore a risk of losing this essential renewable energy resource. A study done by Howorth (1992) in Tanzania on Management of fuel wood reported that fuelwood energy is wasted by many residents by not managing the amounts used and so women manage to use less wood more efficiently by spending more time over the fire, ensuring that flames are direct and not wasted outside the cooking pot and that every scrap of wood and charcoal remaining from the fire is saved for later use.

The low adoption of rationing of both wood fuel is assumed to be due to availability of other forms of wood fuel such as pigeon peas stems, maize stalks and woodlots which the residents relied as alternative sources of firewood and the notion that putting a lot of wood in a stove, one cooks fast. Non rationing of wood fuel implies unnecessary use of wood and so unsustainable utilization. The research found a significant relationship between rationing of wood fuel and the number of days taken to consume a bundle of 20Kg of dry wood (df=1 and 158, F=462.898, p=0.00). This means by rationing wood fuel it would take longer to consume one bundle of 20 kg fuelwood and this is a fuel saving strategy.

5.4.2 The Practice of Splitting of Wood fuel

Majority respondents in Mwala (70%) and in Kibauni (88%) do not practice splitting of wood before burning (Table 4.8). As a result there is great wastage of the wood fuel since much of the heat energy is not channeled to the cooking vessel.

Using better stoves without employing improved practices at the same time is to lose the full benefits of energy-saving that might be achievable. Thick logs burn slowly and often incompletely. Smaller pieces of wood, with a greater surface area, ignite faster and burn more completely and efficiently with no sacrifice in heat output. Sticks with a diameter of 3-5cm are best for cooking and are easy to handle (UNCHR,2002).

Most residents in the study areas did not practice splitting of wood presumably because of non-awareness of the relationship between splitting of wood and total energy usage. Again most households did not have relevant tools like axes to help do the splitting. The study showed a significant relationship between splitting of wood and the number of days taken to utilize one bundle of 20 kg of dry wood (df= 1 and 158, F= 83.2, p=0.00). The interpretation is that splitting wood ensures successful combustion and convergence of fire within the cooking vessel hence energy conservation which favors wood fuel usage and so a bundle of 20kg would take more days.

5.4.3 The Practice of Putting off Fire after use

The practice of putting off fire after use was not commonly practiced in the study areas. This was confirmed by 66% of respondents in Mwala and about 81% in Kibauni not practicing it (Table 4.9). If fire is not put off after use, the excess wood burn unnecessarily and much energy is wasted leading to high fuel usage.

These results are consistent with the findings of Wanjala and Obwoyere (2015) that most residents leave the fire to die out after cooking regardless of how hot it was on completion of cooking task which was purely wastage of fuel.

Low level of adoption of putting off fire after use was presumed to be due to lack of knowledge on its implication in energy loss or availability of alternative fuel sources which made the households reluctant to save excess wood for future use. The study revealed a significant relationship between putting off fire after use and the number of days taken to consume one bundle of wood (df=3 and 156, F=57.292, p=0.00.). This means that putting off fire after cooking saves amount of fuel used per meal and so a bundle takes longer time. By adopting this practice fuel usage is decreased and forests are conserved.

5.5 Number of days taken to utilize one bundle of 20 Kg of dry wood

The research in the two study areas established that majority of households which was 69% in Mwala and 84% in Kibauni utilized a bundle of 20Kg of dry wood in two (2) days (Table 4.12).

Although in the two study sites most respondents utilize it in two days, Kibauni had more households who did the utilization than Mwala because some households had larger land under natural vegetation which made wood fuel more available than Mwala, hence warranting more usage. Also it could be due to the fact that households in Kibauni had established woodlots to complement the natural vegetation for fuelwood. It could also imply that in Mwala households had begun embracing the use of improved stoves which reduces pressure on wood fuel usage.

The results differ with that of Agea *et a*l, 2010 that the volume of the firewood used per year varies from 0.30 m^3 to 3.01 m^3 depending on the size of the household, with an average volume of 1.56 m^3 for an average household family size of seven persons. Taking the relative density of dry wood at moisture content 12%- 15% to be 0.78 (Meler, 2008) and density to be 1000Kg/m^3, this gives a mass of 1217 Kg per year which reduces to 4kg of wood per day and so a bundle of 20kg dry wood would have been utilized in five (5) days. Using proportions if the mean family size was to be six (6) like that of Mwala and Kibauni (Table 4.2 and Table 4.3) the bundle would have been utilized in about four (4) days but the households in the study areas utilized it in two (2) days (Table 4.12).
The variation could have been due to the fact that households in the study areas majority of them use the traditional three stone stoves (Table 4.4) which with its low energy efficiency is very wasteful in wood fuel consumption hence a bundle was utilized in fewer days. Anova Test showed that there was significant relationship between the type of stove and the number of days taken to consume one 20kg bundle of dry wood (df=1 and 158, F=8.187, p=0.005).

The households in the study areas revealed that supply of wood fuel was scarce whereby 71% in Mwala and 67% complained of wood fuel scarcity (Table 4.11). The use of the traditional stove that utilizes wood fuel excessively with no mechanisms of energy conservation amidst a situation of wood fuel scarcity implies non sustainability in the utilization of wood fuel.

5.6 Alternative Energy sources used by the Households

The results of Mwala Sublocation showed that none of the respondents i.e. (0%) had biogas, 16 households representing 19% had solar power, 11 households representing 13% had electricity and 56 households representing 67% did not have any of these energy sources (Table 4.13). Considering Kibauni sublocation, none of the respondents had biogas (0%), 23 households representing 28% had solar power, 7 households representing 8% had electricity and 47 households representing 57% did not have any of these alternative energy sources (Table 4.13).

A similar research done by Wachera (2014) in Nyeri, on challenges of adopting biogas technology found that 35.8% of the respondents utilized biogas energy. This results differed from those of both Mwala and Kibauni where none of the respondents used biogas energy source since Nyeri County being a dairy production zone whereby many people are known to keep dairy animals in Zero grazing system which produce a lot of cow dung.The non-adoption of biogas as an alternative energy source in both Mwala and Kibauni Sublocations is probably due to lack of sufficient information interms of its importance, low gas production, installation cost as reported by Wachera (2014) that low gas production, lack of proper technical expertise, poor attitude and high cost are key factors contributing to low adoption of biogas energy source.

The results of solar energy adoption indicate a slight difference whereby only 19% in Mwala and 28% in Kibauni sublocations were utilizing this energy source (Table 4.13 but the difference was not significant (Z=-1.559, p=0.119). Based on the data more households in Mwala opted for electricity (13%) as compared to Kibauni (8%) and so this caused the difference in adoption of solar power. Generally the level of adoption of solar power in the two sublocations is low. A similar research done by Mukami (2016) in Kiambu on solar energy technology adoption at household level revealed 48% of the respondents were using solar energy at household level. This difference is due to the fact that technological expertise and economic status of households in Mwala and Kibauni is lower and this is indicated by the low adoption of the different energy sources.

The adoption of electricity by households of Mwala and Kibauni sublocations was low with Mwala registering (13%) and Kibauni (8%), (Table 4.13) but the difference was not significant (Z=0.8325, p=0.406). The high cost involved in installation of electricity could have been the cause as reported by Kageni (2015) through a research on evaluation of rural electrification in Meru- South Subcounty where 36% of the respondents adopted electricity and gave cost and distance from the transformer as factors that mainly affected electricity adoption.

In Mwala and Kibauni sublocations it was revealed that 67% and 57% respectively of the households had no access to either biogas, solar or electric power but there was no significant difference in the percentage of the households who did not access these energy sources in the two sublocations (Z= 0.8487, p= 0.3953). This means that the households rely majorly on wood fuel for heating and cooking purposes as reported in the SREP plan for Kenya (2011) that most population rely on traditional fuels such as wood, charcoal, dung, and agricultural residues for cooking and heating. Over reliance of households on wood fuel without complementing with another energy source will negatively affect the forest ecosystem.

5.7 Challenges faced in adopting Biogas energy as an alternative energy source.

The campaigners involved in environmental protection advocate for renewable energy sources like biogas since it has less carbon and so safe. The findings of the research indicated that poor acceptance/uptake and lack of technical knowledge on how to earness biogas energy were the major challenges faced by residents of Mwala sublocation with 34% and 31% responses respectively

A similar scenario was recorded in Kibauni whereby the two factors, poor acceptance and lack of technical knowhow registered 31% and 40% responses respectively (Table 4.14) but the difference of the two factors in both the study areas were not significant. The stakeholders who deal with marketing biogas materials and educating the residents on the application of biogas should take this opportunity.Whenever the residents don't use alternative energy source, it means the main energy source is wood fuel and this threatens vegetation. A study done by Amigun and Musango (2009) on anaerobic biogas generation in rural Africa revealed same results that poor acceptance of biogas by communities and low technical expertise as some of the contributing factors affecting biogas commercialization.

5.8 Challenges faced in adopting solar power as an alternative fuel over wood fuel

Kenya has the advantage of receiving considerable amount of solar insolation although this varies from region and season. If the conversion ability of the solar gadget is good, this energy can be converted to electric energy. The research found that high initial cost of materials required was the major challenge in Mwala and Kibauni with 75% and 82% of households respectively confirming that (Table 4.15). The fact that solar energy is available, there is therefore need for stakeholders who deal with marketing of solar materials to subsidize their materials for the households to afford them. A research done.by Komor, (2009) on solar and wind electricity, challenges and opportunities found that solar photovoltaic (PV) and concentrating solar power (CSP) generating plants produce electricity at costs which are significantly high.

5.9 Challenges faced in adopting electricity as an alternative energy over wood fuel

Electricity services is crucial for socio economic development of a nation despite its low adoption by households in sub-Saharan Africa due to various reasons. In the research area it was found that distance from the transformer was the major challenge hindering households from getting electricity connection with 65% in Mwala and 68% in Kibauni respectively reporting this challenge (Table 4.16).In this case the longer the distance from the transformer, the more the electricity poles required and the higher the cost of connection.Most of the households collect wood fuel from the nearby forests, bushes or cut wood from the planted wood lots making wood fuel relatively cheaper. Without an alternative energy source like electricity, there is therefore over dependence on wood fuel which in turn endangers the available forests. The results agree with the findings of Mbaka, 2015 in a research on evaluation of electricity adoption dynamics in Meru South that distance from the transformer which happens to be the peak point of electricity connection was the greatest barrier in receiving electricity connection.

5.10 Advantages of Biogas as an Alternative Energy Source.

Biogas technology to date is being viewed as an energy source with less problems to the environment hence environmentally sustainable considering the raw materials required. The study revealed that environmental sustainability and promotion of good health were cited as the major advantages besides others like availability of raw materials. In Mwala and Kibauni 36% and 49% of the households respectively agreed that environmental sustainability is a major advantage. In terms of promoting environmental health in Mwala and Kibauni the study revealed 33% and 26% response respectively.

Biogas is renewable energy and it involves anaerobic digestion which utilizes wastes from slaughter houses, animal dug, human excreta and plant materials. Its production does not endanger forests, water sources or the ozone layer neither does it produce harmful gases hence environmentally sustainable and promoter of good health.The results concur with Amigun and Musango (2009) that Biogas improves health of the rural people by providing a cleaner cooking fuel thus avoiding health problems like sneezing, nausea, headache, dizziness, eye irritation and respiratory illnesses and is environmentally sustainable.

5.11Advantages of Solar Power as an Alternative Energy Source

Solar power is one of the renewable energy sources with a very large remaining resource potential that is commercially available and technically proven, and is a focus of considerable policy attention to solve rural energy problems. In the research area, Mwala Sub location, majority of the households i.e. 45 households representing about 54% agreed that solar power slows global warming by producing electricity that does not cause air pollution. Other advantages mentioned included reliability whereby 32 households representing about 39% said solar power is reliable since the rising and setting of the sun is consistent (Table 4.18). In Kibauni Sub location 34 households representing 44% reported that solar power slows global warming effect and 33 households representing 43% said it is reliable (Table 4.18). The results indicate that the respondents are conversant with the goodness they can achieve if they install power cells at home to reduce the burden of collecting wood fuel which is scarce and its utilization is not sustainable.

The results agree well with the findings of Zachary (2013) in his article on the advantages and disadvantages of solar power that solar power with efficient solar panel systems that create electricity without producing global warming pollution is now very clearly one of the most important solutions to the global warming crisis. On reliability he concurred with the findings of the research that the rising and setting of the sun is extremely consistent all across the world, it is known exactly when it will rise and set every day of the year and that there is fairly good seasonal and daily projections for the amount of sunlight that will be received in different locations.

5.12Advantages of Electricity as an Alternative Energy Source

Electrical energy is a critical facet to a country‘s socio-economic development as well as human socio-economic well-being and so most households in rural areas and even urban areas aspire to have electrical connection. In the study areas the advantages of business diversification, improvement in education level and clean and quality lighting were provided as key advantages of electric energy. In Mwala majority of the households i.e.32 households representing about

39% were of the opinion that electricity provides clean and healthy lighting and 28 households representing about 34% said electricity improves education level (Table 4.19).

According to the responses of Mwala households, clean and quality lighting were the leading advantages of electricity. In Kibauni sublocation unlike in Mwala, majority of the households i.e. 31 households representing 40% were of the opinion that electricity helps in business diversification and 27 households representing 35% reported that it provides clean and quality lighting (Table 4.19). In this case business diversification and quality lighting were the leading advantages for Kibauni households.

The results are in agreement with findings by Maleko (2005) that with availability of electricity there is diversification of business activities within the same household. It also concurs with IEA (2008) who noted that rural electrification may affect education not only by improving the quality of schools resulting from their use of electricity-dependent equipment but also by increasing time allocation for studying at home. Again on quality of light the results agree with the finding of Chaurey *et al.* (2004) whose study found out that the initial use of electricity in rural areas is household lighting because electric light is much brighter than that provided by wood fuel and kerosene lamps

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter comprises of general overview of the various types of stoves and the level of adoption of energy saving measures in the study areas.The chapter has also considered recommendations for policy, practice and action by the stakeholders in the energy sector.

6.2 Conclusion

This study found out that the traditional three stone stove was the most popular type of stove in the study areas Mwala having about 93% of the households and Kibauni 96% households using it on daily basis. Improved stoves have not so far found their use with the households in the study areas since very low percentage of households made use of them.This study concludes that for the cooking energy supply to be sustainable in Mwala Sub-County it is required that more households should shift from the traditional stoves to more efficient stoves.

The study also revealed low adoption of the practice of rationing of wood whereby 84% in Kibauni and 65% in Mwala did not practice wood rationing. Considering the practice of splitting wood before use majority of respondents in Mwala (70%) and in Kibauni (88%) did not practice it. In the process much of heat energy is channeled outside the cooking vessel. The study also confirmed low adoption of the practice of putting off fire after cooking as a way of conserving wood fuel for future use whereby 66% of respondents in Mwala and about 81% in Kibauni did not practise it. If fire is not put off after use, the excess wood burn unnecessarily and much energy is wasted leading to high fuel usage. There is therefore a risk of losing much of our vegetation which is an essential renewable energy resource through improper utilization patterns which do not put into consideration energy conservation behaviors.

In the study it came out clear that the three alternative energy sources ie biogas, solar and electricity were not being utilized by majority of the respondents. For biogas none of the respondents in Mwala and Kibauni had access to it, solar energy 19% and 28% of respondents in Mwala and Kibauni respectively utilized it and electricity 13% in Mwala and 8% in Kibauni had access to it. From the same findings it was revealed that 67% and 57% of respondents in Mwala and Kibauni respectively did not have access to the three mentioned alternative energy sources.

In a situation whereby most residents have no access to either biogas, solar or electricity will imply over reliance of wood fuel as the sole energy source for household purposes which in turn impacts negatively on vegetation and the general environment

It is evident from the results that majority of the households' exhibited utilization patterns that led to wastage of wood fuel and unnecessary energy lose. This was shown by the low adoption level of energy saving measures that included rationing of wood fuel, splitting of wood and putting off fire after use despite the high demand for fuel wood and scarce supply. The low adoption led to excess usage of wood fuel where a bundle of dry wood was utilized by a family size of six members in only two days. Again the type of stove that proved popular was the traditional three stone stove that excessively uses wood fuel and produces much smoke that is a health risk and a contributor of greenhouse gases production. This rendered the utilization of wood fuel unsustainable in the study areas given that much land had been cleared for agricultural purpose and that wood supply had been reported to be scarce making the households turn to use of crop residues or travel long distances and using much time in search of wood fuel.

6.3 Recommendations

From the results of this study, the following recommendations were made;

1.There is need for aggressive campaign in dissemination of improved stoves and related technology in order to reduce pressure on forest and other woodlands in Mwala sub-county. For instance the fixed brick stove which is long lasting, uses local materials and can accommodate several cooking vessels need to be initiated for use in the study areas.

2. The residents of Mwala and Kibauni sublocations need to embrace energy saving measures like rationing of wood fuel, splitting wood before burning it and putting off fire after cookingto reduce the quantity of wood fuel consumed at household level and hence reduce pressure on forests.

3.There is need to ease the connection charges by for example subsiding the cost of electricity connection or by providing long term fee spread over years.

4.An Energy Centre needs to be established in the Mwala sub-county which will act as the focal point for dissemination of energy efficient technologies. The energy centre will help to provide information and market the alternative energy sources such as biogas and solar which the households in the study areas have not utilized fully.

5. Initiatives promoting planting of trees in forms of woodlot, agroforestry or as hedges in farms should be encouraged. Re-afforestation and afforestation efforts in the area should be given full support by the government as a way of working towards achieving a 10% forest cover. This will help counteract wood fuel scarcity as found from the research.

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APPENDICES

Appendix 1:Questionnaire

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Questionnaire: SUSTAINABLE UTILIZATION OF WOOD FUEL SURVEY

Personal Details:

1. Name of the respondent and Phone Number.

   ....

2.Name of the Ward………………………………………

3.What is your family size? ………………..

Stove and fuel (Objective 1)

4.What Type of biomass fuel do you use commonly for cooking purpose: a) firewood b) charcoal c) LP Gas.

5. What type of stove/jiko do you commonly use/? a) Traditional 3 stone jiko b) improved jiko

6. What factor makes you like the stove/jiko above a) Economic factors b) Cultural factors c) Technical factors.

2. In case you use an improved stove which type do you use? a) Fixed stove b) portable all Metal jiko c) portable clay lined d)Ecozoom/smokeless
3. Assume you are cooking Githeri and you start cooking at 4pm when will it be ready a) 5pm

b) 6pm c) 7pm e) 8pm

4. Do you commonly experience cases of overcooked food? A) Yes b) No
5. Does your kitchen have chimney or ventilation? A) yes b) no
6. What are some of the challenges you face while cooking? Tick appropriately a) excess heat b) a lot of smoke c) coughing d) eye irritation e) no problem at all

Level of adoption of energy saving measures (Objective 2)

7. Do you weigh/ration the amount of wood fuel to use per day? A) yes b) no
8. For how many days do you use a full bundle of wood fuel? a) 3 b) 4 c) 5 c) 6 e) 7
9. When cooking do you split/break logs of wood before putting in the jiko a) yes b) no
10. Do you put off the excess burning wood after use? a) yes b) no
11. Have you ever been trained on energy saving techniques? A) Yes b) No
12. According to you how is supply of your wood fuel ? a) scarce b) high supply
13. How many hours do you take to collect firewood and back? a)1-2 b)3-4 c)0ver 5
14. How many times do you use charcoal per week?………………………
15. Where do you get your charcoal from? a) Buy b) make at home
16. Do you ration/weigh the amount of charcoal to use? a) yes b) no
17. In most cases do you put off the excess burning charcoal after use? a) yes b) no

Alternative energy sources used by the households(Objective 3)

18. From the list below which other alternative energy source do you use in your household? a) Biogas b) Solar c) Electricity d) None
19. What are the challenges faced by the communities in using the alternative sources of energy?
20. What advantages would the alternative energy sources have over firewood?

Appendix2: Comparative Useful Energy contents of stoves

	Unit	LPG	Firewood		Charcoal	
Stove		**Standard**	**Traditional**	**Improved**	**Traditional**	**Improved**
Energy	Mj/Kg	46	16	16	29	29
Content	-	45	12	20	20	28
Efficiency %			1.92	3.2	5.8	8.12
Useful Energy						

Source: MOE, 2002 Report

Appendix 3: Splitted logs of wood

Appendix 4: Dry maize stalks

Appendix5: Dry pigeon peas stems

Appendix6: A Simple Kitchen

Appendix7: A Clay Lined/Ceramic Stove

Appendix8: Woodlots planted in the home compound

Appendix9: Traditional Three Stone Stove

Appendix 10: Fixed Brick Stove