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Adoption of Green Energy Technologies in Selected Peri-Urban and Rural Areas of Makueni and Machakos Counties, Kenya

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***Abstract*— Many peri-urban and rural households use traditional stoves which have low energy use efficiency leading to wasteful use of woodfuel, increase in indoor air pollution and putting more pressure on biomass sources. Energy saving devices have been introduced which are environmentally friendly and economical. The main objective of this study was to assess levels of adoption of green energy technologies in selected peri-urban and rural areas of Makueni and Machakos Counties, Multistage sampling technique was used whereby; locations and sub-locations were selected purposefully. Households from four sub-locations were chosen using simple random sampling. A total of 214 households in the four selected study areas were interviewed. The study used questionnaires and interview schedules for data collection. The collected data was coded and entered into the computer for analysis using the Statistical Package for Social Sciences (SPSS) and statistics and data software (STATA) presented using tables. Utilization of metal charcoal energy device was higher than that of other charcoal devices in Unoa area (63.1%). Family size had a significant effect on use of LPG ($\chi 2$ = 22.010, P = 0.001) and electric energy technology ($\chi 2$ = 20.482, p = 0.002). The study results on the prediction of future charcoal energy devices adoption showed that in the next 30 years' majority of the households will still prefer Kenya ceramic charcoal stoves to the maendeleo charcoal stoves. The outcome of the research is useful to many stakeholders including the government, Ministries of Agriculture and Energy, Environmentalists, Market Suppliers of green energy devices and Researchers.**

***Index Terms*— Green energy, Adoption level, woodfuel, peri-urban and rural..**

I. Introduction

Most of the persons in Kenya count on wood fuel. High market price of petroleum prevents the needy from using kerosene and Liquefied Petroleum Gas (LPG) to using biomass fuels such as dung, firewood plus charcoal (UNEP, 2017). Presently, the need for woodfuel overtakes supply (FAO, 2022). Improved energy technologies have higher combustion efficiency which sanctions them to bring forth a significant amount of heat as well as less smoke hence less wood usage (Kimaro, *et al.*, 2017). These technologies diminish the amount of heat lost to the surrounding environment by about 30% (Doggart & Meshack, 2017).

This means that the public's full acceptance and adoption of the woodfuel and solar power-saving technologies will go a long way toward reducing the demand for woodfuel and preserving forests, reducing women's household chores, improving indoor air quality, and helping to save a significant amount of money that would otherwise be spent on fuel purchases (Kimaro, *et al.*, 2017). Land degradation rises as the usage of biomass increases. By depriving the soil of nutrients that would have been recycled back into the soil, the use of manure and agricultural leftovers as fuel leads to further degradation of the land. Due to inadequate yields from degraded land's poor soils, an increase in land degradation causes an increase in poverty and hunger (Gauri, 2019). This study is also in line with Kenya's efforts to achieve the Sustainable Development Goals (SDGs), since the adoption of energy-saving devices will free women and children from the strain of spending hours searching for wood fuel; they will be able to engage in more productive activities like farming and small businesses. This will help reduce severe poverty and hunger. Improvement of indoor air quality will also lead to an increase in mother health and a decrease in infant mortality. According to studies, even though the majority of underprivileged people accept indoor air pollution as a way of life, using clean energy sources like solar electricity can dramatically improve people's health by lowering indoor air pollution levels (Tun, 2019).

Significance of the study

The outcome of the research is helpful to the government, Ministry of Agriculture and Ministry of energy as they continue to promote the design and use of energy-saving technologies. This study will help in strategizing and reducing the disparity between the rural and peri-urban households' in adoption of improved energy technologies. Adoption of improved energy technologies is one way in which a nation's environment can be conserved. Predicting improved energy technology adoption and utilization scenarios will help in the intervening strategies to mitigate against the unsustainable energy utilization and environmental degradation.

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In both rural and peri-urban settings, there is an information vacuum regarding the adoption rates of improved firewood stoves, improved charcoal stoves, and fireless cookers of Makueni (MICDP, 2018) and Machakos (MICDP, 2018) Counties. Information on social-economic factors influencing the acquisition and use of the same technologies in these Counties is limited and thus the need for this study. There is also limited literature relating to the use of biogas, wind power, energy-saving stoves and solar technologies in the study areas. Further, there has not been prediction of future adoption scenarios of these energy utilization technologies in the selected study households (areas).

A. Importance of Energy to the Economy

In the world today, about 100 million people face fuel shortages as wood fuel supplies diminish (FAO, 2017). Statistics by FAO, (2018), state that wood fuel provides more than 70 percent of energy in 34 developing countries and more than 90 percent in 13 countries (including 11 in Africa). In Kenya, more than 85% of people still use traditional fuels such wood, charcoal, as well as agricultural waste for cooking and heating. (Pilishvili, *et al.*, 2016). However, for most economies, especially the developing economies, only the conventional types of energy (petroleum, electricity) are considered while computing Gross National Product (GNP). Energy is now widely acknowledged to be a necessary but insufficient condition for economic progress (Federal Emergency Management Agency (FEMA), 2007). Most if not all the developing countries rely on biomass energy as opposed to other forms of energy like electricity and petroleum. At the individual level energy fulfils basic human demands for cooking, lighting as well as heating, while it plays a decisive role in employment and income creation at the national and local levels (Mills, 2016).

Households, enterprise sectors (including industry, large, small, and medium enterprises), building and construction, *jua kali*: transport, agriculture, service sectors (Information and Communication Technology, financial and banking, and tourism), basic services - health, education, water, electricity generation, and government - civil and military - are just a few of the various economic sectors that depend on energy (Tun, 2019). According to UNEP, (2017), wood fuel consumers include rural households, peri-urban and also urban households, industries and institutions. However, studies generally categorize consumers of energy in Kenya into five sectors: household, commercial, manufacturing, transport and agricultural (IEA, 2015). The same broad categories are supported by Bhagavan, (1996) who states that the Kenyan economy relies on six different types of energy: wood fuel, petroleum fuels, electricity, ethanol, wind and solar, with the last two sources of energy being limited in use.

B. Global Environmental Challenges and Energy Needs

Global emissions of greenhouse gases into the atmosphere have been abruptly exaggerated especially in the last ten years **(**IRENA**,** 2018). Without enough time for the capital basis of natural resources to regenerate, this has led to extensive environmental damage (Bergmann, 2019). According to Doggart & Meshack, (2017), worlds emissions and cumulative emissions are estimated to be 6.7 billion tons of carbon by 2050. The over exploitation, depletion, and degradation of natural capital, including ecosystem products and services and natural resources, have been caused by this economic expansion, often known as the "brown economy. Sub-Saharan Africa has also the lowest electricity rate worldwide. In 2008, it was 28.5% which means that as many as 587 million people were without access to electricity (World Bank, 2017). United Nations' Food and Agriculture Organization (FAO) has estimated that in the coming decades the total fuel wood consumption will continue to grow. This is promoted also by the population growth and the rising fuel prices (FAO, 2019). The likelihood of land degradation will rise when food and energy production take place in the same region. While many individuals are need to expend a great deal of time and effort to meet their daily energy needs, East Africa might be said to be experiencing chronic power poverty (FAO, 2019). In Kenya, wood fuel meets the energy demands of the traditional sector, which includes rural communities and the urban poor. Petroleum and electricity are the main drivers of the modern sector of the economy (UNEP, 2017).

C. Global Wood fuel situation

In 2000, there were over 3.9 billion cubic meters of wood produced, of which 2.3 billion cubic meters were utilized for wood fuel. This means that almost 60% of all wood harvested from forests and non-forest areas around the world is used for energy purposes (FAO, 2018). Thus efforts need to be made to reduce the demand for wood biomass and thus conserve the forests and the environment. Asia and Africa produce over 75% of the woodfuel (African Development Bank (AfDB), 2017). The projections of global woodfuel consumption by 2010 ranged from 1.5 billion m^3 to 4.25 billion m^3 (FAO, 2018).

D. Wood fuel situation in Africa

Over 90% of the wood harvested from forests in Africa is used as fuel. The bulk is used as wood fuel directly, while a variable but significant amount is converted into charcoal. Charcoal is the most significant source of domestic energy in many African cities, with more than 80% of it being utilized in urban areas (FAO, 2018). The most significant biomass is wood, but the reliance on it varies across many different countries. Some nations, like Nepal in Asia, Kenya, Uganda, Rwanda, and Tanzania in Sub-Saharan Africa, rely at least 80% of their entire energy needs on wood fuels. Table 2.1 shows that there will be greater demand for wood fuel by the year 2030 in Africa and yet there is a scarcity in its supply currently. Therefore, it is necessary to introduce technologies that reduce the use of woodfuel in order to make its use sustainable and to promote afforestation and re-afforestation.

Table 1: FAO projections of woodfuel consumption in Africa from 1970 to 2030

YEAR	1970	1980	1990	2000	2010	2020	2030
Fuel-wood (million m^3) Africa	261.1	305.1	364.6	440.0	485.7	526.0	544.8
Charcoal (million tons) Africa	8.1	11.0	16.1	23.0	30.2	38.4	46.1

According to Tun (2019), statistics provided by Camco Global show that woodfuel is one of the major causes of environmental degradation and accounts for about 18% of the world's GHG (greenhouse gases). Most households in developing countries use traditional stoves, for example the three stone and the metallic charcoal stoves which are less efficient in energy saving. The issue of over-exploitation of forested lands is one that many Sub-Saharan African nations face. In terms of biomass yield, large areas that were formerly very productive have been utterly exhausted. Estimates show that excessive clearing and poor management result in the annual loss of about 11 million hectares of tropical forests (FAO, 2018). This removes the ground cover, rendering the land susceptible to soil erosion and hastening land deterioration. It also reduces one of the main sources of wood fuel, leading to a fuel shortage

E. Wood fuel situation in Kenya

An estimated 40.5 million tonnes of biomass are needed in Kenya today, but only 16 million tonnes are available sustainably (UNEP, 2017). Biomass energy (mainly firewood and charcoal) constitutes 70 per cent of the national energy supply, 90 per cent of which is consumed by households (Lambe, 2015). The most important energy sources in Kenya still are, and will continue to be, firewood and charcoal. Over 90% of people use firewood for cooking and warmth, making it mostly a rural fuel. With 82% of the population living in cities using charcoal, cities are where it is most commonly used. Because there is less wood available, certain regions of the country use agricultural waste and animal dung as a source of cooking energy (Sikei, *et al.*, 2009). Since cooking is one of the most energy-efficient end uses, woodfuel must be improved because it is a major source of energy in rural areas of many developing nations. One way to achieve this is by substituting the upgraded stove for the conventional "three stones" method (World Bank, 2019). In Makueni, 77.9% of total residents use firewood while 10.6% use charcoal (MCSP, 2019). More research is needed to determine how this valuable resource may be used responsibly because it plays such a significant part in the majority of Kenyans' daily lives. According to Oduor & Githiomi, (2012), the conservation of wood energy should be given a priority through the promotion of improved and green stoves with higher efficiency.

1. Adoption of Renewable Energy Technologies in Kenya

According to International Energy Agency (IEA, 2017), the energy obtained from unlimited sources, rapidly replenished or naturally renewable are termed alternative sources of energy. The Kenya Vision 2030 indicates that energy transition is primal to the realization of the socioeconomic pillars within the development framework of the vision. It stipulates that the government is committed to continuing institutional reforms in the energy sector and that new sources of energy will be found through the exploitation of renewable energy (Pilishvili, *et al.*, 2016). The vision acknowledges that energy connects the overall development of all the remaining pillars. Accordingly, the ministry of energy is making efforts to include the usage of renewable energy sources in the energy mix. The Scaling-Up Renewable Energy Program in Low-Income Countries (SREP), from which Kenya is one of the six pilot countries to benefit, is one of these obvious measures (Pilishvili, *et al.*, 2016). Most rural catchments count on paraffin and wood fuels to match their daily energy demands.

F. Worlds view on biomass energy saving stoves

In the late 1990s and early 2000s, there emerged the second generation of cooking stoves, which, while more expensive, were constructed of more durable materials. Examples can be found in both Latin America and China. In Latin America, the Plancha so-named because of its prominent metal griddle (*plancha*) was disseminated under Guatemala's social fund program. A more expensive, durable stove lasting a decade or more, the Plancha has a metal top used for roasting corn and preparing tortillas and other staple foods, a shelf for feeding wood, space on top for placing cooking utensils and equipment, and a chimney for venting smoke. Having a durable stove with many convenient features, combined with the freedom to select options it led to a high degree of continued stove use (Johnson Chiang, 2015). China's experience provides ample evidence that the development of a program for better cooking stoves can succeed, given that more than 100 million improved cooking stoves are still in use. China has achieved the largest improvement in energy efficiency as a result of its programs in the 1980s and 1990s (Yang, *et al.*, 2014). According to Papada & Kaliampakos, (2020) the failure to adopt better charcoal stoves in urban Zanzibar was mostly attributed to poor quality of the improved stoves, pricing, information, and education on the stoves.

People base their purchases of devices on actual prices, according to Elvira (2008), and are generally unaware of the operational costs. According to IRENA (2018), technology diffusion is limited by the unavailability of information and proposes that the best sources of information are the people who have already adopted the technology. One nation with a successful improved stove program is China, which by the early 1990s had distributed 120 million upgraded stoves to rural areas (Johnson & Chiang, 2015).

G. Energy saving stoves *(jikos)* in Kenya

According to Njenga, *et al.*, (2017), in Kenya there are modern woodfuel saving stoves which include; **Kenya Ceramic Stoves**- the Kenyan Ceramic Stoves (KCJ) is a light, portable charcoal burning stove consisting of two distinct units- a metal cladding and a ceramic liner. ***Kuni Mbili*** **Stove** is a cook stove that is designed to take two pieces of firewood at a time (Wafula, *et al*., 2000). ***Maendeleo*** **Stove-** a device developed to replace the three stones with an inbuilt ceramic liner that is inverted, bell-bottom shaped with an opening for feeding woodfuel, and V-shaped pot rest **Woodfuel energy-** Energy or heat obtained from the burning of woody biomass (either firewood or Charcoal) Muchiri, (2008). **Stoves star**-According to Muchiri, (2008) and Wafula, *et al*., (2000), a Stove Star is easy to light, saves on Charcoal consumption, is safe, easy to use and maintain, efficient, long-lasting and portable. ***Kunimbili*** **stove-**This is a highly efficient wood stove which can also use charcoal. It's especially designed to reduce charcoal consumption, and carbon monoxide emission and last longer. *Kunimbili* stove is easy to light, saves on woodfuel consumption, is safe, easy to use and maintain, efficient, long-lasting, portable and comes with a 6 months' warranty (Majid, 2006). According to Githiomi, *et al.*, (2011), by assuming that households that were using three-stone fires with an efficiency of 10% will gradually switch to more efficient technologies like upgraded firewood and charcoal stoves, the adoption of efficient technological devices will help to reduce the deficiencies in woodfuel. This suggests that a sizable amount of wood fuel will be conserved, lowering consumption.

Scode gasifier stove -According to (Lotter, *et al.*, 2015), this is a single pot forced draft front loading concrete highly efficient cooking stove that has a fan that is powered by either solar or battery or electricity. The fan provides air for the complete burning of wood fuel hence reducing smoke emissions (Njenga, *et al.*, 2017). It has a capacity of sixty (60) litres and can cook for up to 150 persons. Scode gasifier stove uses multiple fuels e.g. firewood, pellets, charcoal, dry maize cobs etc., is fitted with a solar or electrically powered (low consuming) fan, saves up to 50% of the wood fuel, reduces smoke emissions by 60%, cooks faster than a normal stove and is long-lasting (Jeffery, *et al.*, 2015). ***Kisasa*** **stove** -According to (Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI), 2016), *kisasa* stove a portable pottery cylinder (ceramic liner) that is installed by building mud or concrete surrounding the kitchen. It is suitable for use in households and institutions with a permanent fireplace. *Kisasa* stove is easy to install and maintain, is easy to light, saves on woodfuel consumption, produces less smoke and more efficient than the traditional 3 stone fire.

Rocket stove -A Rocket stove is a firewood burning stove. There are three types: Mud, mud-brick and cement brick rockets. It cooks faster, is fairly affordable and reduced emission to the environment. The sizes vary with each household and/or institution. It saves on woodfuel consumption, are easy to use and maintain, produce less smoke, is easy to light, cook faster, safe to use, long lasting and 6 months' warranty (Karekezi & Kithyoma, 2002). **Institutional stoves** are highly efficient, large heavy-duty cooking stoves that use firewood. They save on fuel costs, time and energy Muchiri, (2008). **Fireless cooker (food warmer).** This is an insulated basket, container or box that is especially 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 up to eight (8) hours after cooking (Mugo & Gathui, 2010). This cooker reduces the consumption of wood fuel by about 40%.

H. Solar energy base in Kenya

Kenya is located along the equator where there is adequate radiant energy from the sun which is the most important parameter when exploiting solar resources (Broesamle, *et al.*, 2011). Kenya has year-round Direct Normal Irradiance (DNI) of 6 kWh per m2, which is suitable for solar thermal uses and energy generation. Communities should aim to employ solar energy technologies since they are the most practical low-carbon options for supplying their lighting and cooking needs, as well as a variety of other energy needs at the domestic and industrial levels. (Ministry of Energy, 2004). According to Duffie & Beckman, (2013) the main solar appliances which are either powered by sunlight, either directly or through electricity generated by solar panels include; solar panels, solar lamps, solar torches, solar chargers, solar batteries, solar air conditioning, solar balloon, solar charger, solar backpack, solar cell phone charger, strawberry tree, solar chimney, solar calculator, solar-powered waste compacting bin, solar cooker, solar dryer, solar-powered fan, solar furnace, solar inverter, solar keyboard and solar lamp (Foster, *et al.*,2009). Solar pond, solar road stud, solar street light, solar traffic light, solar *tuki*, solar-powered flashlight, solar notebook, solar-powered calculator, solar-powered desalination unit, solar-powered pump, solar-powered fountain, solar-powered radio, solar-powered refrigerator, solar-powered stirling engine, solar-powered watch, solar-pumped laser, solar roadway, solar Spark lighter, solar still, solar tree, solar vehicle, solar boat, tûranor planet solar solar bus, solar car, solar golf cart, solar panels on spacecraft, solar sail, solar thermal rocket, solar operated automatic milk Collection unit, tracker, windmill, fan, computer, solar water heater and solar holiday lights (Smith, 2011).

II. RESEARCH METHODOLOGY

A. Study areas

The study area fell within Makueni and Machakos County each having two study sites which were rural and peri-urban. The rural study sites included Kilili sub-location in Makueni County and Kinoi Sub-location in Machakos County while the peri-urban sites included Unoa sub-location in Makueni County and Mung'ala sub-location in Machakos County.

1. Makueni County Study Sites

The choice of the study sites was informed by their accessibility. Unoa Sub-location in Wote Sub-County, Makueni County, was one of the study sites in Makueni

County. This site has in the recent past witnessed increased demand for both charcoal and firewood as the most common source of fuel by the surrounding urban dwellers. The area is also characterized by the clearance of indigenous trees and shrubs to create room for horticulture farming which has a ready market at Wote town owing to its proximity (Kieti, *et al.*, 2016). This in turn has led to a scarcity of fuel wood due to the clearance of trees. The overspill of both commercial and residential developments into the agricultural fields in the area has also led to an acute shortage of vegetation (Bhatta, 2010). Wote Sub-County, has five locations which include Kako, Kikumini, Muvau, Nziu and Wote. Wote location has two sub-locations, Kamunyolo and Unoa where the study was conducted.

The second study site was Kilili Sub-location in the Nzaui/Kilili/Kalamba ward in Makueni County. The information on the green economy most likely may not have reached this area hence using the only available government forest (Nzaui forest) and available trees in their home gardens as a source of wood fuel. The Nzaui forest is already invaded by the residents for charcoal and firewood leading to deforestation (MICDP, 2018). Population, Area in Sq. Km and Density by Administrative Units of Kilili Sub-location.

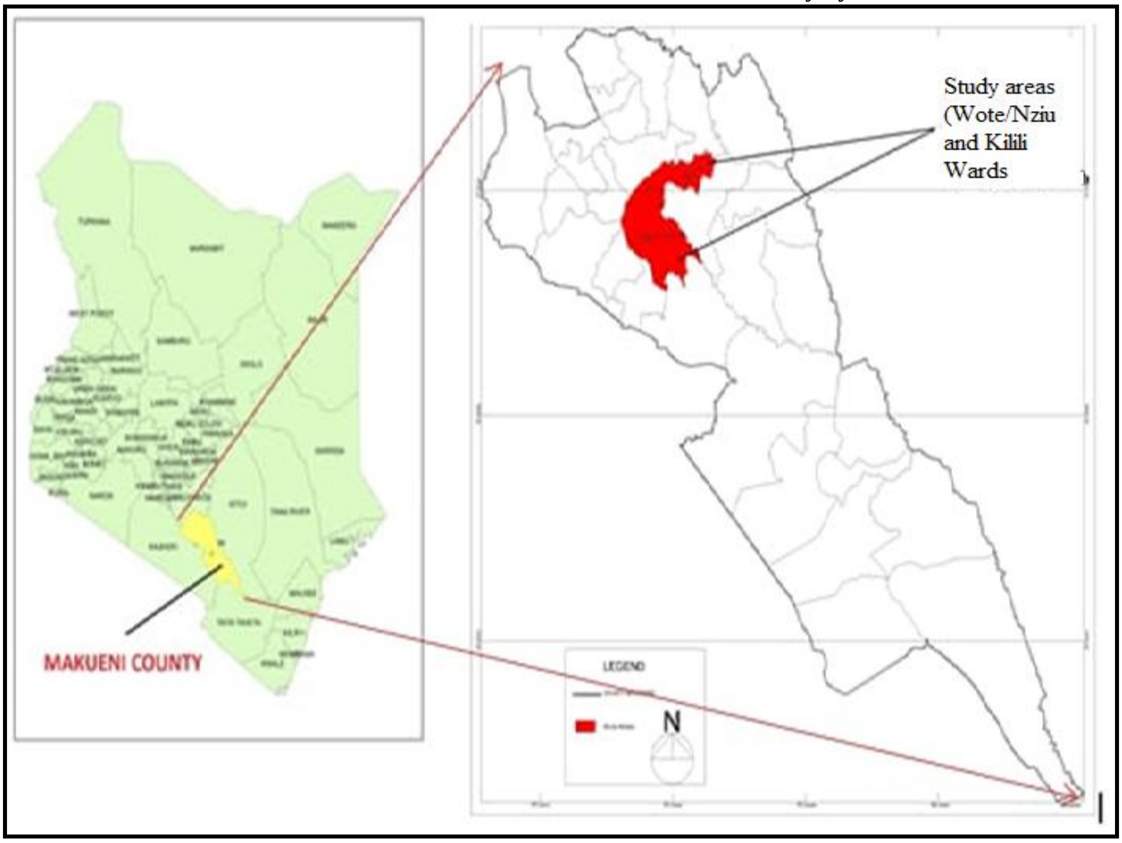

Figure 1: Location of Makueni County in Kenya
Source: Makueni development plan, 2013

2.MACHAKOS COUNTY STUDY SITES

The study sites included Machakos central Sub-County where a peri-urban site was selected in Mung'ala Sub-location (Ecological Zone 2/3) and Kinoi Sub location in Kalama Sub-County (Ecological zone 4) which is in rural parts of Machakos (MICDP, 2018). In Kalama Sub-County the study was conducted in Kinoi sub-location in Kyangala location which is in rural areas of Machakos County. The choice of the study site was based on several considerations emanating from the research problem. This area is characterized by deforestation due to forest encroachment by the households for the source of wood fuel. Other areas have been cleared for agricultural activities mostly arable farming; this has led to limited sources of energy fuel hence the need of adopting energy-saving technologies. Bare rocks have been left with little or no soil covering most parts of the study area. The area has steep hills and experiences the highest soil erosion compared to other Sub-locations in the Sub-County (Muloo, *et al.*, 2019).

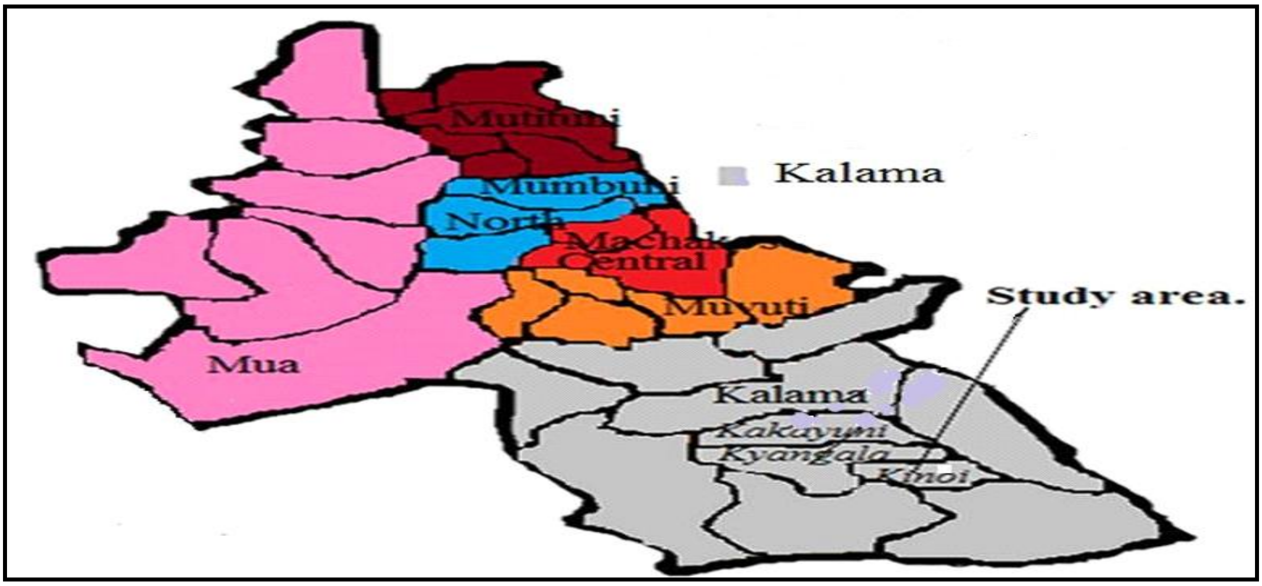

Figure 2: Location of study area; Kalama Sub-County in Machakos County Source: Machakos development plan, 201

MUMBUNI LOCATION MACHAKOS CENTRAL DIVISION

Mumbuni location is in Machakos Central Sub-County and the study area is within the Mung'ala Sub-location which boulders Iveti forest on the upper side of the division. Other sub-locations include Kasinga, Upper Kianda, Lower Kianda and Misakwani. The study area has been deforested for agricultural practices mainly cash crops including coffee, French beans and fruits. Its nearness to the Machakos town has also led to a dense population hence vegetation clearing has been high for settlement. This gives the need for energy-conserving technologies adoption to conserve the available woodfuel and vegetation in general hence limited greenhouse gas emissions.

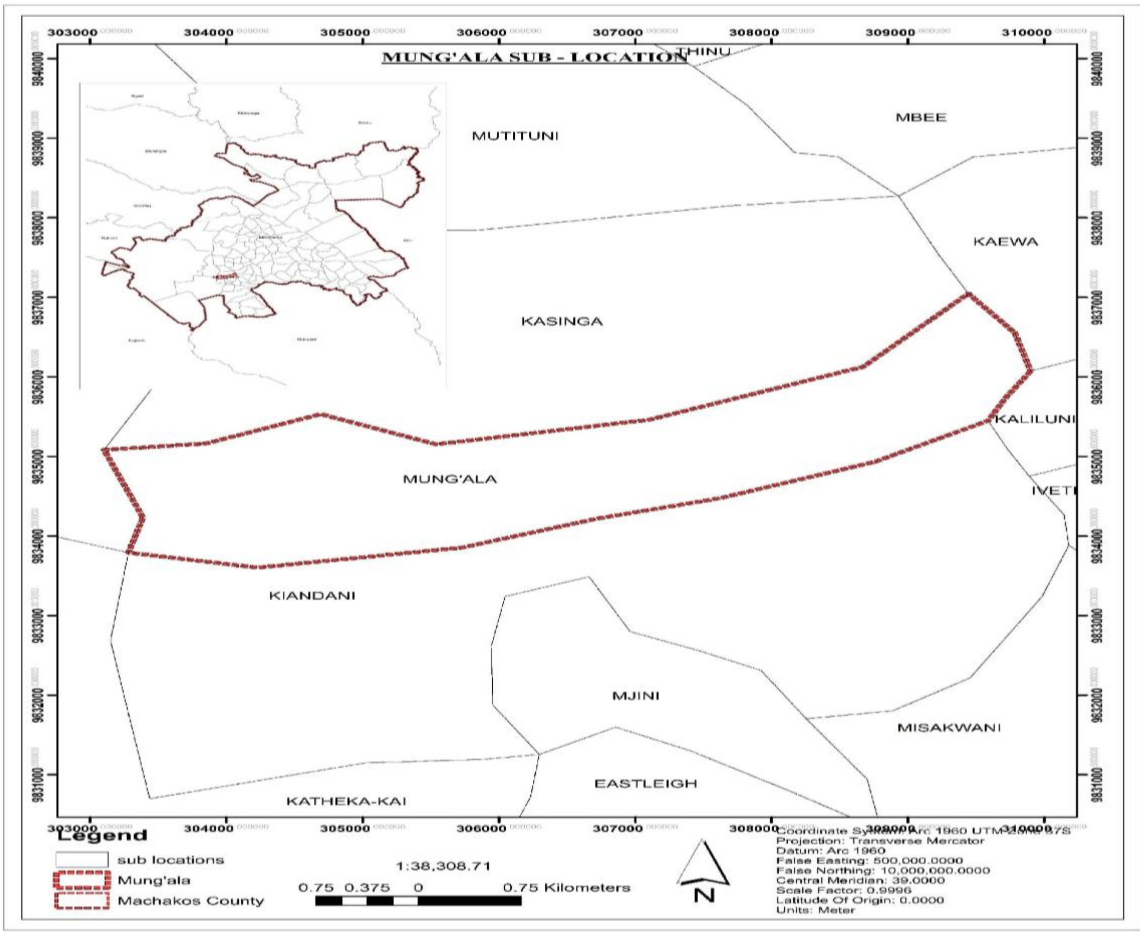

Figure 3: Location of study site; Machakos Central Sub-County in Machakos County

Source: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, FAO, NPS, NRCAN, Geo Base, IGN, Kadaster NL, Ordinance Survey, Esri Japan, METI, Esri China (Hong Kong), © Open Street Map contributors, and the GIS User Community.

B. Research Design

The design of this study was based on survey research in which data was collected for the objectives of the study. The research was based on the study of social-economic factors influencing the adoption of woodfuel energy-saving stoves and the use of solar power technologies in selected peri-urban and rural sub-locations of Makueni and Machakos County. The choice of survey research was motivated by the following factors; survey research provides a suitable instrument for collecting a large amount of data, it provides a practical framework for collecting a large sample of composing groups and survey studies have strong data reliability. Also according to Orodho (2005), survey concerns describing, recording, analyzing and reporting conditions that exist or have existed. The survey design was relevant to this study as the research will report on the socio-economic characteristics of the respondents in the study area and the adoption of renewable energy transfer technologies. The research was designed to collect data from respondents in peri-urban and rural households, and key informants on the adoption of renewable energy.

1. Sample Size and Sampling Procedures

According to Mugenda & Mugenda (1999), sampling is a procedure, process or technique of choosing a sub-group from a population to participate in the study. This sub-group is carefully selected to be representative of the whole population with the relevant characteristics. In the current study, the sampling frame consisted of peri-urban and rural sites, Unoa and Kilili sub-locations, Makueni Sub-County in Makueni County and Mung'ala sub-location in Mumbuni location and Kinoi Sub-location in Kyangala location, Kalama Sub-County all in Machakos County. Multistage sampling technique was used whereby; the locations and the sub-locations were selected purposefully.

Sample size formula for a known population by (Etikan & Babtope, 2019).

$$n = \frac{\dfrac{Z^2\, x\, P(1-p)}{e^2}}{1+\left[\dfrac{Z^2\, x\, p(1-p)}{e^2 / N}\right]}$$

N= Known Population size (1689)

Z= z score at 1.96 (confidence level used 95%)

P= sample proportion (0.2)

e = margin of error at 0.05

$$\text{Therefore: } n = \frac{\dfrac{1.96^2\, x\, 0.2x0.8}{0.05^2}}{1+\left[\dfrac{1.96^2\, x0.2x0.8}{0.05^2\, /1689}\right]} = 214.7$$

Using this formula, 214 households were selected from a total of 1689 households in the study areas (Kilili 52, Mung'ala 59, Kinoi 56 and Unoa 47 households) Table 3.4. A sample size of 214 (12.7%) lies between 10% to 30% (Mugenda & Mugenda (2013).

Table 2: Sample size in study areas

Location	Sub-location	Household	Sample size	%
Kilili	Kilili	378	52	13.8
Mumbuni	Mung'ala	550	59	10.7
Kalama	Kinoi	543	56	10.3
Wote	Unoa	218	47	21.6
Totals		**1689**	**214**	**12.7**

Data collection strategy involved reconnaissance surveys and site selection having site familiarization. Pre-visit tour to Unoa, Kilili, Kinoi and Mung'ala Sub-Locations for consultation with village elders was carried out. The Household survey involved the administration of questionnaires to the household through interviews. Data collected included types of improved energy technologies used in the selected peri-urban and rural sub-locations of Makueni and Machakos Counties. Lastly administration of key informants' survey questionnaire on identification of agents of energy suppliers and examining the innovation transfer process was done. In the household survey, combined random walk, systematic sampling and quota method (Robert, 1997) were used in the Sub-locations.

2. Methods of Data Collection

According to Mugenda & Mugenda (1999), questionnaires give detailed answers to complex problems. Primary data was sourced mainly from the households through the administration of a questionnaire at the study sites. The head of the household was interviewed in each case but in his/her absence the eldest son or adult in the household was targeted for the interview. This intended to obtain correct and reliable information. The observation was also used as a means of obtaining primary data. Observations would provide rich qualitative data with supported data from interviews and discussions. In-depth investigations were conducted through observation of some of the biogas technologies, wind power technologies, wood fuel energy saving and solar power technologies used in the households. Secondary data was sourced from among others; the County Integrated Development plans, the central bureau of statistics documentation, reviews of relevant official records and selected policy documents. The interview guide was used to derive responses from energy suppliers and government officials since it generally yields the highest cooperation and lowest refusal rates, offers high response quality and takes advantage of the interviewer's presence and it is multi-method data collection that combines questioning, cross-examination, probing techniques (Kabir, 2016).

3. Data management

This was done through observation and by the use of questionnaires. After collection, the data was processed and analyzed to answer the research questions. The questionnaires were first checked for completeness clarity and consistency. The answers were then coded before data entry. Inferential statistics were used to analyze the data. Smith (2011) asserts that inferential statistics are used to infer conclusions about a population. To ensure that the sample is representative, it uses random sampling techniques. Descriptive statistics such as frequencies and cross-tabulations were used in summarizing the numerical data to describe the data and the patterns arising from the analyzed data. Besides descriptive statistics, inferential statistics were used to determine and quantify the relationships between the dependent variables such as the adoption of woodfuel energy-saving technologies and solar power technologies; these included Chi-square test. The results of the data analysis were presented in regression tables. Lastly implications from the different data sets were integrated logically.

III. RESULTS

The data obtained was subjected to statistical analysis using statistical package for social sciences (SPSS) and statistics and data software (STATA). Results are presented in figures and tables to give a clear picture of the presence,

adoption, factors influencing adoption and future scenarios of green energy devices.

Green energy uses in Makueni and Machakos Counties

Adoption of green energy devices in the respective areas indicated that in Unoa, higher usage of charcoal energy devices (98.5%) was detected. In Kilili, the highest adopted energy technology was that of woodfuel energy (93.5%). This was similar to the adoption of would fuel in Kinoi where majority, (93.2%) of the respondents adopted woodfuel energy technologies. In Mung'ala area, the most utilized energy technologies were that of electricity (98.2%), table 3.

Table 3: Adoption of green technologies by the respondents in the study area

Green energy technology used	Unoa	Kilili	Kinoi	Mung'ala
Charcoal energy devices	64(98.5%)	21(67.7%)	53(89.8%)	40(72.7%)
LPG	39(60.0%)	0(0.0%)	10(16.9%)	45 (81.8%)
Solar energy devices	57(87.7%)	11(35.5%)	35(59.3%)	7(12.7%)
Woodfuel energy	58(89.2%)	29(93.5%)	55(93.2%)	27(49.1%)
Electricity	12(18.5%)	4(12.9%)	31(52.5%)	54(98.2%)

A. Green Energy Technology Devices Used by the Respondents in the Study Area

Utilization of *maendeleo* charcoal energy device was higher than that of other charcoal devices in Unoa area. (24.6%). Kenya Ceramic is the most utilized charcoal energy device in Kilili (35.5%), Kinoi (49.2%) and Mung'ala (61.8%). Use of solar energy devices was not noted in all the areas. In the four study areas, the most utilized solar energy was solar lamps. This was followed by Solar powered radio (1.8%) in Mung'ala whereas in Kinoi, the second most utilized solar energy device was solar heater (1.7%). In Kilili area, the second most utilized solar energy device was solar charger (9.7%) whereas in Unoa, the second most utilized solar energy device was solar batteries (27.7%). Woodfuel energy devices were mainly utilized in Unoa and Kilili area residents. The most utilized device was *udongo* woodfuel in Unoa (6.25%), and Mung'ala (14.5%). Electric devices were not commonly utilized in all the four areas. Mung'ala area had 6 electricity devices, being the highest utilization of electric devices. This was followed by Unoa and Kinoi which had utilization of five devices. Electric lamp was utilized in Kilili (12.9%). In Unoa, most of the respondents (7.7%) utilized electric heater whereas in Mung'ala (52.7%) utilized electric lamps. Utilization of electric lamp was also found to be in Mung'ala (52.7%), table 4.

Table 4: Adoption of green energy technology devices by the respondents in the study area

Improved energy technology used	Type used	Unoa	Kilili	Kinoi	Mung'ala
Charcoal energy devices	Kenya ceramic	6(9.2%)	11(35.5%)	29(49.2%)	34(61.8%)
	Maendeleo	16(24.6%)	0(0.0%)	0(0.0%)	5(9.1%)
	Kisasa	1(1.5%)	0(0.0%)	1(1.7%)	0(0.0%)
Solar energy devices	Solar powered radio	3(4.6%)	0(0.0%)	0(0.0%)	1(1.8%)
	Solar panel	1(1.5%)	0(0.0%)	0(0.0%)	0(0.0%)

	Solar heater	0(0.0%)	0(0.0%)	1(1.7%)	0(0.0%)
	Solar lamps	20(30.8%)	8(25.8%)	28(47.5%)	6(10.9%)
	Solar torches	4(6.2%)	0(0.0%)	0(0.0%)	0(0.0%)
	Solar chargers	11(16.9%)	3(9.7%)	0(0.0%)	0(0.0%)
	Solar batteries	18(27.7%)	0(0.0%)	0(0.0%)	0(0.0%)
Woodfuel energy	Improved firewood stoves	1(1.5%)	0(0.0%)	0(0.0%)	0(0.0%)
	Udongo wood fuel	4(6.2%)	0(0.0%)	0(0.0%)	8(14.5%)
	Kuni mbili stove	0(0.0%)	1(3.2%)	2(3.4%)	0(0.0%)
	Kisasa stove	0(0.0%)	0(0.0%)	1(1.7%)	0(0.0%)
Electricity	Microwave	1(1.5%)	0(0.0%)	0(0.0%)	2(3.6%)
	Refrigerator	1(1.5%)	0(0.0%)	1(1.7%)	4(7.3%)
	Electric lamp	0(0.0%)	4(12.9%)	24(40.7%)	29(52.7%)
	Visual/audio machine	0(0.0%)	0(0.0%)	1(1.7%)	14(25.5%)
	Electric oven	0(0.0%)	0(0.0%)	0(0.0%)	1(1.8%)
	Electric cooker	3(4.6%)	0(0.0%)	4(6.8%)	0(0.0%)
	Electric heater	5(7.7%)	0(0.0%)	1(1.7%)	0(0.0%)
	Waffle iron	2(3.1%)	0(0.0%)	0(0.0%)	4(7.3%)

B. Advantages of Using Green Energy Technologies

The respondents stated major advantages of using the sources of energy as;

Charcoal energy devices: Readily available (24.8%), easy to operate (16.8%), easy to maintain and cheap for the respondents (12.1% respectively). Table 5.

LPG energy: Less time spent in acquiring (14.0%), easy in operation (6.1%) and easy to maintain (5.1%). Table 5.

Solar appliances: Are mainly easy to operate (7.5%), readily available (5.6%), cheap to obtain (4.7%) and can accommodate several household members (3.3%). Table 5.

Electric energy: was noted by the respondents to be easy to operate (9.8%), cheap to obtain (2.8%), easy to maintain (4.7%) and readily available (2.3%), table 5.

Table 5; Reasons for using green energy technologies

Reason for using energy technology	Charcoal energy	LPG	Solar appliance	Electric energy
Readily available	53 (24.8%)	5 (2.3%)	12 (5.6%)	5 (2.3%)
Cheap to obtain	26 (12.1%)	3 (1.4%)	10 (4.7%)	6 (2.8%)
Easy to maintain	26 (12.1%)	11 (5.1%)	11 (5.1%)	10 (4.7%)
Easy to operate	36 (16.8%)	13 (6.1%	16 (7.5%)	21 (9.8%)
Less time spent cooking	15 (7.0%)	1(0.5%)	0(0.0%)	1 (0.5%)
Less time on collecting	10 (4.7%)	30 (14.0%)	0(0.0%)	2 (0.9%)
Less impact on economies	5 (2.3%)	0(0.0%)	090.0%)	00.0%)
Can accommodate several HH members	7 (3.3%)	7(3.3%)	7 (3.3%)	6 (2.8%)
Other reasons	36 (16.9%)	144 (67.3%)	158 (73.8%)	142 (66.2%)

C. Disadvantages of Utilizing the Green Energy Sources

Despite the usage of these energy sources, the respondents noted some disadvantages of the devices and reported these as depicted in table 4. 10a and table 6b.

Utilization of charcoal energy: Has the disadvantages of leading to environmental pollution (25.7%), expensive to obtain (15,9%), is the cause of occurrence of diseases and it takes more time to be collected (8.9% respectively). Table 6a.

Use of LPG energy had disadvantage that it is expensive (22.9%), costly to maintain (12.6%), requires more time to acquire (1.9%) and is limited to a few number of household members (1.4%). Table 6a.

Solar energy devices are expensive (23.8%), less durable (7.5%), costly to maintain (7.0%) and limited to a few household members (5.6%). Table 6b.

Hydroelectric energy has a disadvantage of being expensive to obtain (18.2%), costly to maintain (14.0%), less durable (18.2%) and requires high technical skills (5.1%). Table 6b.

Woodfuel energy causes environmental pollution (33.2%), needs more time spent in collecting/ purchasing (21.5%), leads to more time spent on cooking (12.6%), limited to few number of household members (4.7%) and leads to more occurrence of diseases (3.7%), table 6b.

Table 6a: Disadvantages in the usage of green energy sources

Energy source	**Disadvantages in the use**	**Frequency (N = 214)**	**%**
Charcoal energy	Leads to environmental pollution	55	25.7
	Expensive to obtain	34	15.9
	Less durable	16	7.5
	More cause to occurrence of diseases	19	8.9
	More time spent on collecting	19	8.9
	More time spent cooking	16	7.5
	Limited to a few number of HH members	13	6.1
	Costly to maintain	6	2.8
LPG Energy	Leads to environmental pollution	0	0.0
	Expensive to obtain	49	22.9
	Hardly available	2	0.9
	High technical skills in operation	7	3.3
	More time spent on collecting	4	1.9
	More time spent cooking	1	0.5
	Limited to a few number of HH members	3	1.4
	Costly to maintain	27	12.6

Table 6b: Disadvantages in using the improved technology devices

Energy source	Disadvantages in the use	Frequency (N = 214)	%
Solar appliances	Leads to environmental pollution	1	0.5
	Expensive to obtain	51	23.8
	Less durable	16	7.5
	More cause to occurrence of diseases	1	0.5
	High technical skills in operating	9	4.2
	More time spent cooking	1	0.5
	Limited to a few number of HH members	12	5.6
	Costly to maintain	15	7.0
Hydroelectric energy	Expensive to obtain	39	18.2
	Less durable	16	18.2
	More cause to occurrence of diseases	1	0.5
	More time spent on collecting	1	0.5
	More time spent cooking	1	0.1
	Limited to a few number of HH members	2	0.9
	Requires high technical skills	11	5.1
	Costly to maintain	30	14.0
	Hardly available	1	0.5
Woodfuel devices	More time spent in collection or purchasing	46	21.5
	More time spent in cooking	27	12.6
	More environmental pollution	71	33.2
	Causes to occurrence of diseases	8	3.7
	Limited to a few number of HH members	10	4.7
	Expensive	2	0.9
	Less durable	2	0.9

D. MAINTENANCE OF THE GREEN CHARCOAL ENERGY SOURCES

Choice of the green charcoal technology is affected by maintenance cost of the device used. Average maintenance cost of Kenya Ceramic stoves (20.1%) and *maendeleo* stoves (5.1%) was below Ksh. 300. Average maintenance cost of charcoal *kisasa* stove (0.9%) was Ksh. 301 – 600. This showed that green charcoal energy technology (ceramic stove, *maendeleo* and charcoal kisasa stove) were viewed by most of the respondents as cheaper to maintain.

Table 7: Maintenance cost of green charcoal energy devices

Energy device	Maintenance cost (Ksh.)	Frequency (N = 214)	%
Ceramic stove	Below Ksh.300	43	20.1
	Ksh. 301 – 600	17	7,9
	Ksh. 601 – 900	17	7.9
	Above Ksh. 900	4	1.9
	Non committal	133	62.1
Maendeleo stoves	Below Ksh.300	11	5.1
	Ksh. 301 – 600	5	2.3
	Ksh. 601 – 900	1	0.5
	Above Ksh. 900	4	1.9
	Non committal	193	90.2
Charcoal *kisasa* stove	Ksh. 301 – 600	2	0.9
	Non committal	212	99.1

E. Maintenance of LPG energy device

Results of this study revealed high cost of maintenance of LPG gas energy devices. On the average, cost of maintenance of LPG gas cooktop (24.8%) was above Ksh. 900 similar to maintenance of gas heater (0.5%).

Table 8: Maintenance cost of LPG energy devices

Energy device	Maintenance cost (Ksh.)	Frequency (N = 214)	%
LPG gas cooktop	Below Ksh.300	13	6.1
	Ksh. 301 – 600	8	3.7
	Ksh. 601 – 900	15	7.0
	Above Ksh. 900	53	24.8
	Non committal	125	58.4
Gas heater	Below Ksh.300	0	0.0
	Ksh. 301 – 600	0	0.0
	Ksh. 601 – 900	0	0.0
	Above Ksh. 900	1	0.5
	Non committal	213	99.5

F. Maintenance cost of solar energy devices

Respondents gave their opinion on the cost of maintenance of solar energy devices and stated that maintenance of solar panel was ksh. 301 – 600 (0.5% of the respondents) while on average, maintenance of solar torches and solar lamps was below Ksh. 300 (1.9%). Average maintenance of solar battery was Ksh. 301 – 600 as stated by 5.6% of the respondents. However, 1.9% of the respondents noted that average maintenance of solar powered radio was comparatively expensive and it was Ksh. 601 – 900.

Table 9: Maintenance cost of Solar energy devices

Energy device	**Maintenance cost (Ksh.)**	**Frequency (N = 214)**	**%**
Solar panel	Below Ksh.300	0	0.0
	Ksh. 301 – 600	1	0.5
	Ksh. 601 – 900	0	0.0
	Above Ksh. 900	0	0.0
	Non committal	213	99.5
Solar lamps	Below Ksh.300	37	17.3
	Ksh. 301 – 600	14	6.5
	Ksh. 601 – 900	12	5.6
	Above Ksh. 900	0	0.0
	Non committal	151	70.6
Solar torches	Below Ksh.300	4	1.9
	Ksh. 301 – 600	0	0.0
	Ksh. 601 – 900	0	0.0
	Above Ksh. 900	0	0.0
	Non committal	210	98.1
Solar batteries	Below Ksh.300	5	2.3
	Ksh. 301 – 600	12	5.6
	Ksh. 601 – 900	5	2.3
	Above Ksh. 900	1	0.5
	Non committal	191	89.3
Solar powered radio	Below Ksh.300	3	1.4

	Ksh. 301 – 600	1	0.5
	Ksh. 601 – 900	4	1.9
	Above Ksh. 900	0	0.0
	Non committal	210	98.1

Maintenance cost of electricity devices

This finding shows that to maintain Audio/ visual appliances and electric cooker generally requires more than Ksh. 900 (7.0% and 1.9% respectively). The cost required for maintenance of electric oven (0.5%), waffle iron (1.9%), refrigerator (0.9%) and electric lamps (16.4%) require below Ksh 300. However, to maintain electric heater the cost is Ksh. 301 – 600 (1.4%), table 10.

Table 10: Cost of maintenance of Electricity devices

Devices	Cost of maintenance	Frequency (N = 214)	%
Microwave	Below Ksh.300	0	0.0
	Ksh. 301 – 600	1	0.5
	Ksh. 601 – 900	0	0.0
	Above Ksh. 900	1	0.5
	Non committal	212	99.1
Electric Oven	Below Ksh.300	1	0.5
	Ksh. 301 – 600	0	0.0
	Ksh. 601 – 900	0	0.0
	Above Ksh. 900	0	0.0
	Non committal	213	99.5
Electric waffled iron	Below Ksh.300	4	1.9
	Ksh. 301 – 600	1	0.5
	Ksh. 601 – 900	0	0.0
	Above Ksh. 900	1	0.5
	Non committal	208	97.2
Refrigerator	Below Ksh.300	2	0.9
	Ksh. 301 – 600	1	0.5
	Ksh. 601 – 900	1	0.5
	Above Ksh. 900	0	0.0
	Non committal	210	98.1
Electric cooker	Below Ksh.300	0	0.0
	Ksh. 301 – 600	2	0.9
	Ksh. 601 – 900	0	0.0
	Above Ksh. 900	4	1.9
	Non committal	208	97.2
Electric lamps	Below Ksh.300	35	16.4
	Ksh. 301 – 600	12	5.6
	Ksh. 601 – 900	10	4.7
	Above Ksh. 900	0	0.0
	Non committal	157	73.4
Electric heater	Below Ksh.300	1	0.5
	Ksh. 301 – 600	3	1.4
	Ksh. 601 – 900	2	0.9
	Above Ksh. 900	2	0.9
	Non committal	206	96.3
Audio/ visual appliances	Below Ksh.300	0	0.0
	Ksh. 301 – 600	2	0.9
	Ksh. 601 – 900	1	0.5
	Above Ksh. 900	15	7.0
	Non committal	196	91.6

G. Cost of Maintenance of Firewood Energy Devices

The respondents were asked to indicate the costs they incurred in firewood energy devices for maintenance. This result indicated that the respondents (3.7%) spend Ksh. Below 300 for *udongo* woodfuel. It was further noted that 0.9% of these people used mainly Ksh. 300 – 600 in maintenance of *Kuni mbili jikos* (0.9%). This finding showed that it was a bit affordable to maintain *udongo* woodfuel *jiko*, table 11.

Table 11: Cost of maintenance of firewood energy

Devices	Cost of maintenance	Frequency (N = 214)	%
Udongo woodfuel *jiko*	Below Ksh.300	8	3.7
	Ksh. 301 – 600	1	0.5
	Ksh. 601 – 900	0	0.0
	Above Ksh. 900	0	0.0

	Non committal	205	95.8
Kuni mbili jiko	Below Ksh.300	1	0.5
	Ksh. 301 – 600	2	0.9
	Ksh. 601 – 900	0	0.0
	Above Ksh. 900	0	0.0
	Non committal	211	98.6

IV. CONCLUSIONS

A. Adoption of the green energy technologies

According to International Energy Agency (IEA, 2017), the energy obtained from unlimited sources, rapidly replenished or naturally renewable are termed alternative sources of energy. Use of green technologies in the respective areas indicated that in Unoa, higher usage of charcoal energy devices. In Kilili, the highest used energy technology was that of woodfuel energy. This was similar to the usage of would fuel in Kinoi where majority of the respondents used woodfuel energy devices; this could be attributed to availability of woodfuel in the homestead forests. In Mung'ala area, the most utilized energy was that of electricity. Wind energy was not used in this County; hence the need for implementation of Scaling-Up Renewable Energy Program in Low-Income Countries (SREP) as stated by Pilishvili, *et al.*, (2016). Kenya Ceramic is the most utilized charcoal energy device in Kilili. These findings are confirmed in studies undertaken by Njenga, *et al.*, (2017), who stated that Kenya ceramic stoves are modern energy saving stoves. In the four study areas, the most utilized solar energy technology was solar lamps. Woodfuel energy technology was mainly utilized in Unoa and Kilili area. Electric devices were not commonly utilized in all the four areas; most likely due to high maintenance cost. Mung'ala area had 6 electricity devices, being the highest utilization of electric devices. Utilization of electric lamp was also found to be in Mung'ala area. This is in agreement with UNEP, (2017), which noted that petroleum and electricity are the main drivers of the modern sector of the economy.

Information together with education regarding the stoves were found to be the vital points leading to the let-down of high adoption of green charcoal stoves as also noted by Papanda & Kaliampakos, (2020), that the failure to adopt better stoves was mostly attributed to poor quality of the improved stoves, pricing, information, and education on the stoves. The respondents stated major advantages of using the sources of energy as; Charcoal energy devices: Most of the respondents in the four areas reported that they use these energy devices because they are readily available. Charcoal energy technologies are easy to operate, easy to maintain and cheap for the respondents; since it is the most significant source of domestic energy in many African cities and rural areas with more than 80% of it being utilized in urban areas (FAO, 2018). LPG energy devices were mainly preferred and regarded as less time spent in acquiring. They were stated as easy in operation, easy to maintain, reduce emission to the environment and lead to less deforestation. Solar appliances: Are mainly easy to operate, readily available, cheap to obtain and can accommodate several household members. Electric energy devices: were noted by the respondents to be easy to operate, cheap to obtain, easy to maintain and readily available.

Despite the usage of these energy sources, the respondents noted some disadvantages of the devices and reported that utilization of charcoal energy: Has the disadvantages of leading to environmental pollution, expensive to obtain, is the cause of occurrence of diseases and it takes more time to be collected; even though presently the need for woodfuel overtakes supply as stated by FAO, (2022). Use of LPG energy devices had disadvantage that they were expensive, costly to maintain, requires more time to acquire and is limited to a few number of household members. On the other hand, solar energy devices are expensive, less durable, costly to maintain and limited to a few household members. Hydroelectric energy devices have a disadvantage of being expensive to obtain, costly to maintain, less durable and requires high technical skills in installation. Woodfuel energy devices causes environmental pollution, needs more time spent in collecting, leads to more time spent on cooking, limited to few number of household members and leads to more occurrence of diseases. Usage of green energy technology would depend on the distance travelled to acquire the technology. Choice of the green technology is affected by maintenance cost of the device used. However, they noted that average maintenance of solar powered radio was comparatively expensive; explaining the low adoption of the solar powered radio in study area. On contrary communities should aim to employ solar energy technologies since they are the most practical low-carbon options for supplying their lighting and cooking needs, as well as a variety of other energy needs at the domestic and industrial levels. (Ministry of Energy, 2004).

From the results obtained in this study, it can be concluded that:

- Improved energy technologies used in the selected study areas included: charcoal, LPG, solar, Woodfuel and hydroelectric energy.
- There were low levels of adoption of most improved energy technologies in the study areas.

From the results obtained in this study, it is recommended that; there is need for further research in:

i. Adoption of non-improved energy devices vs the improved energy devices
ii. Impacts of education level on adoption of various improved energy devices.
iii. Forecasts on the market sales of improved energy technologies

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CONFLICT OF INTEREST

The research was conducted by the researchers and no conflict of interest arose during and after this research