ENHANCING AVAILABILITY, ACCESS AND USE EFFICIENCY OF BIOMASS ENERGY IN RURAL AGRO-ECOSYSTEMS IN KAKAMEGA COUNTY, KENYA

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DECLARATION

This thesis is my original research work and has not been presented for a degree in any other University.

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DEDICATION

I dedicate this thesis to my parents, who have supported me unconditionally during this process. I sincerely appreciate all of the help and inspiration that I have received.

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ABSTRACT

To date, most rural households in Kenya rely on wood fuel for domestic energy requirements, especially cooking. Increasing population is putting a lot of pressure on tree cover, its role in climate change mitigation and biodiversity conservation notwithstanding. Therefore, assessing the biomass energy value-chain with the view of enhancing rural energy security is a policy option worth consideration. Accordingly, the overall objective of this study was to assess availability, accessibility and value-addition of biomass energy sources within rural households in Navakholo Sub-County, in order to contribute to policy options towards rural energy security, reduced energy footprints and increased tree and forest cover in the region. Spatial analysis using GIS procedures was used to track and map trends in land use and tree cover, hence biomass energy availability from 1990 to 2020. Social survey using questionnaires, Focus group Discussions and key informant interviews were used to gather the human interface with the land use and land cover dynamics focussing on availability, access, use-efficiency, value-addition and management practices around biomass and alternative energy sources. A total of 394 households were sampled through systematic random sampling. Questionnaire data was cleaned, coded and entered into an excel spreadsheet and analysed using descriptive and inferential statistics. Focus Group Discussion and key informant interview data was thematised and subjected to content analysis, and finally used as narratives to enrich the results from the spatial analysis. Trends analysis showed a steady decline in tree and forest cover at 12.02% from 1990 to 2020. Chi square analysis revealed a significant relationship (p=0.000, df = 12) between tree cover and adequacy of fuelwood. Regression analysis showed that households that used charcoal and cow dung had appropriate tree cover. Chi square analysis revealed a significant relationship (p=0.000, df=3) between biomass energy and value addition. There has been an overall decline in tree and forest cover in Navakholo, thus affecting availability of biomass energy. Although Navakholo sub-county is a maize and sugarcane zone, value-addition on agricultural biomass through briquetting is generally non-existent. Much of the maize cobs are directly used as low energy fuel or simply left to rot away. Cow dung is mainly used as manure, instead of being also used as raw material in biogas production, because of the high initial costs. Although charcoal is a value-added product on wood fuel, respondents viewed it only as an energy alternative for those who could afford it. With appropriate exposure and capacity development, briquetting of agricultural biomass, particularly maize cobs has the potential to enhance rural energy security in the area. Overall, decreasing tree cover combined with a lack of value addition on the availability of biomass poses serious environmental implications for the future. As such there is need for an integrated strategy for increasing household tree cover of appropriate species; capacity building in value addition of agricultural biomass and increased adoption of improved cook stoves to enhance use efficiency of biomass energy. Creating incentives for alternative income opportunities to enable households invest in other energy options notably biogas energy, electricity and liquefied petroleum gas merit urgent attention at the national and county policy levels.

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LIST OF ACRONYMS AND ABBREVIATIONS

BF	Bunyala Forest
FGD	Focus Group Discussion
GIS	Geographical Information Systems
GoK	Government of Kenya
HES	Household Energy Security
HWB	Human Well Being
ICS	Improved Cook Stove
KFE	Kakamega Forest Ecosystem
KFS	Kenya Forest Service
KWS	Kenya Wildlife Service
LPG	Liquefied Petroleum Gas
PELIS	Plantation Establishment Livelihood Intervention Scheme
RE	Renewable Energy
SDG	Sustainable Development Goals
SSA	Sub-Saharan Africa
TCS	Traditional Cook Stove
VA	Value Addition

DEFINITION OF TERMS

Availability: The amount of energy resources required to sustain household functions

Accessibility: The duration of time it takes for the customer to reach or acquire energy services

Biomass: Maize cobs, cow dung, wood fuel and charcoal

Biomass energy: Plant and animal matter used as resources for energy purposes. This includes crop residues, wood fuel and cow dung used for energy purposes within the household.

Briquetting: Converting waste agricultural and forestry residues into a solid fuel source with a high energy content (Yi, *et al.*,.2022)

Clean energy: Refers to sources of low carbon energy like hydroelectric and nuclear power. Additionally, it refers to biofuels, wind, solar, and small-scale holder-electric renewable energy (Carley & Konisky , 2020).

Densification: Involves additional increase of energy density and reduction of volume in biomass

Energy infrastructure: Refers to energy resources, technologies and uses within the households

Energy security: Refers to lowering the risks to energy services, which are essential to the operation of modern countries (Axon & Darton , 2021).

Energy services: The advantages energy carriers have for human health. It accepts the idea that "people don't demand energy per se, but energy services like cooking, heating, washing, and mobility, cooling and lights" (Kalt, *et al* 2019).

Fossil fuel: A fuel such as coal oil or gas formed by natural processes such as anaerobic decomposition, formed in the earth from plant or animal remains.

Human Well Being: Involves essentials for a happy life, good health, positive social interactions, security, freedom of choice and actions (World Resources Institute, 2005)

Improved cook stove: A cooking device created and distributed with the intention of resolving issues related to the environment and health brought on by traditional cooking methods (Moses, *et al*., 2019)

Liquefied Petroleum Gas: A kind of fuel made up of liquid hydrocarbon gases

Management practices: Refer to energy saving practises within the household and how households can better enhance energy efficiency

Poor people: If one's income or consumption falls below a predetermined poverty line, one is considered poor (Savadogo, *et al*., 2015).

Pelletization: A procedure where the mechanical – physical properties of the output material are different from the input raw material (Jezerska, Zajonc, Vyletelek, & Zegzulka, 2016). It's a process that occurs at very high pressure and compaction.

Purchase: Denotes an association between the cost of energy service and household income.

Pyrolysis: Heating of biomass in the absence of oxygen producing oil, charcoal and gas

Renewable Energy: Energy derived from naturally occurring, recurring, and continuous energy flows in the surrounding environment (Twidell & Weir, 2015).

Traditional Cook Stove: An open fire stove comprising of three stones.

Value-addition: The process of converting a product from its initial state to one that is more valuable (Hinai & Jayasuriya , 2021)

Value chain: A chain of activities performed to deliver a valuable product for the market (Simatupang, Piboonrungroj, & Williams, 2017)

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Energy is essential to a nation's economy, standard of living, and national security. In 2021, 1.9 billion m^3 of wood fuel was produced globally with Africa and Asia accounting for 37% each (World Bioenergy Association, 2022). Current global concerns on energy include high geopolitical tensions and uncertainty in the energy sector with changes taking place rapidly. Today's pressures are from fragile oil markets, crisis in natural gas markets caused by Russia's cuts to supply, an acute climate crisis with effects caused by fossil fuels and the record heat waves experienced in the world in 2023 (International Energy Agency , 2023). Further, existing energy sources cannot be abandoned. Instead, necessary modifications can be made to reduce their negative environmental impacts. Nonetheless, global demand for energy will continue to increase in supply by 1.3% per year from 2020 to 2030 reaching 670 Exajoules (EJ) by 2030 (International Energy Agency , 2021). From a global perspective, energy saving is key to first world countries however developing countries require more energy to develop therefore the need for renewable energy sources. Fossil fuels are predominantly used to cater for energy demand globally and have dominated the global energy supply since the industrial revolution.

Globally, the main energy drivers are coal, oil, and gas. Their role in climate change provides a case for emphasis shift to renewable energy. Renewable energy sources are sustainable, unlimited and generally clean. There is an increasing evolution and interest regarding biomass as a sustainable energy source. Due to the need for sustainable energy self-sufficiency, biomass's contribution as a resource of renewable energy supply garnered significant attention worldwide in 1970 (Antar , *et al.*, 2021). Further, rekindled interest in biomass energy in the mid-1990s was a means of mitigating the effects of climate change and global warming. Biomass is being researched as a renewable alternative energy resource in this millennium for three reasons: to minimize the exploitation of finite resources like fossil fuels; to reduce greenhouse gas emissions to mitigate global warming; and to lessen reliance on energy imports by producing sustainable renewable energy Therefore, there was interest among countries in employing novel renewable energy sources, like biomass. Additionally, essential to sustainable development is biomass use as a renewable energy source. Current debate on energy supply and demand shows that in order to keep the surface temperature below 2˚C, renewable energy can meet two thirds of the world's energy needs and help reduce greenhouse gas emissions (Gielen, *et al*., 2019).

Well-crafted policies take into account the characteristics of energy systems and supply and demand for energy. Future global energy demands will include a significant increase in energy requirements, a shift towards a low carbon mixture of fossil fuels and adjustments in technological assumptions or specific policy (Ahmad & Zhang , 2020).   . Increased flow rates to the market are typically caused by factors such as energy demand, technological advancements, high prices and related investments, and change.

Comparisons between conventional and non-conventional energy sources show that carbon-intensive energy development has given way to low-carbon, from one-time utilization towards multiple use and from simple production to technological production. The transition from coal to hydrocarbons to new energy sources has seen a reduction in carbon emissions. Due to the dominance of fossil fuel-based power generation, including coal, oil, and gas, as well as an exponential increase in population, there has been an increase in the demand for energy over the past few decades. This has resulted in issues on a global scale related to a sharp increase in carbon dioxide emissions. Since 1850, the world's energy supply has become dominated by the growing use of fossil fuels, which has caused carbon dioxide emissions to spike (Holecheck *et al*., 2022). As a result of anthropogenic activities, the concentrations of CO_2 and other greenhouse gases are rising raising concerns about a 1-5˚C global warming of in the 21st century. From a pre-industrial concentration 280000ppm parts per billion (ppb) to a current concentration of 399500ppb the atmospheric concentration of CO_2 has increased (Siddik, *et al*., 2021)

The sustainable energy transition involves a shift to a new high efficiency system, and the proper management of environmental and social costs are managed sustainably (Chen, *et al*., 2019). There is a strong correlation between income and the availability and affordability of clean fuels for cooking (Ritchie, *et al*.,2019). According to Ritchie et al, (2019), approximately two-thirds of the world's population depended on solid fuels in 1980 including coal, wood, crop residues, cow dung and charcoal. Three decades later, this percentage has dropped, with less than half of the people on the planet utilising solid fuels. Asia is the world leader in the production of electricity generation from renewable energy sources. According to the World Bioenergy Association (2022), Asia produced 43% of the world's renewable electricity in 2019 with the Americas coming in second at 30% and Europe with 24%. Africa's 2.4% share was primarily attributable to hydropower. With 10% of all renewable energy produced globally in 2016, biomass was the largest renewable energy source (70% of all renewable sources), followed by hydropower at 2.5% and other renewables (solar, wind, geothermal and tidal etc.) at 1.5% (Popp, *et al*., 2021)

Europe leads in biogas supply and accounts for 50% of the global supply (World Bioenergy Association, 2019). The findings above show that Africa is still heavily reliant on solid biomass while the developed world is reliant on liquid biofuels and biogas, showing technological innovations in the developed countries. Unsustainable resource extraction has been occurring in Kenya as a result of weak laws and regulations (Obure, 2022). The gradual shift in fuel preference and source is due to the scarcity and rising cost of fuel as families grow and farmlands are divided for housing (Government of Kenya, 2020). . Huge untapped renewable energy resources are abundant throughout Africa including solar and hydroelectric power, geothermal energy in the East of Africa and wind in coastal areas in most countries (Olanrewaju *et al*., 2020). According to Adams & Asante (2020), the energy sector in Africa is dominated by fossil fuel, hydropower, nuclear and biomass. Due to their excessive carbon dioxide emissions, fossil fuels and traditional biomass energy sources (such as wood, charcoal, and animal and agricultural waste) are linked to respiratory diseases, especially in highland areas in Sub-Saharan Africa. As a result, it's necessary to look into alternative clean energy sources (Adams & Asante, 2020).

Presently, around 783 million people lack access to clean cooking fuels (Dioha & Kumar , 2020). According to Dioha (2020), given that traditional biomass and fossil fuels dominate the energy system of most Sub Saharan countries, the situation becomes overwhelming in the context of climate change. In some countries, up to 90% of the energy cooking mix is made up of biomass. The energy needs of the region can be met by Africa's abundant energy resources. The potential of renewable energy sources still remains untapped. Energy forms the foundation which the three Vision 2030 key pillars (Economic, Social and Political Governance are based. To achieve Vision 2030 and socioeconomic growth, Kenya must increase energy generation and improve energy consumption efficiency. Kenya has abundant renewable energy resources. Nearly 80% of the country's renewable energy production came from renewable resources primarily hydro (34%), geothermal 43% resources and other sources (Spittler *et al*., 2021). The technical and economic viability of the country's renewable energy resources, however, has not yet been thoroughly evaluated, mapped out, or appraised. Biomass energy provides 68% of Kenya's energy supply (Government of Kenya, 2020). Kenya has developed policies and laws pertaining to energy, forests and charcoal over time to govern the development of energy. The conservation hypothesis contends that energy conservation polices have a negative effect on the economy, while the growth hypothesis suggests that energy conservation polices that lower energy consumption may have an effect on economic growth (Mutumba, *et al*., 2021). This economic growth and development is impacted by energy development. In Kenya, the primary sources of energy are dominated by biomass fuels (charcoal and firewood) making up 69% of the country's overall energy uptake and 90% among the rural households (Government of Kenya , 2018). This report by the Government of Kenya (2018) states that 45% of the biomass energy is taken from forest cover while 55% of the same is in form of animal wastes, crop residue, and woody biomass from farmlands. Multiple government agencies as well as ministries seek to ensure sustainability of biomass energy through advocacy for the use of improved stoves and continued energy crop production. However, such efforts seem to bear little fruits given that development and research programs in the area of sustainable energy hardly receive adequate funding.

Current estimates from the International Energy Agency state that bioenergy accounts for two thirds of Kenya's energy supply. By 2040 this percentage will drop to 15% as a result of rising oil and geothermal resource consumption. Geothermal energy will produce nearly half of Kenya's electricity by 2040. Electricity generation by source shows that the nation is dependent on renewable sources of energy as geothermal at 45%, hydro- electricity at 28%, wind 13% and thermal oil at 11% (Kenya National Bureau of Statistics, 2020). The report indicated that 88.5% of power generated in the country came from renewable energy sources. Total supply of biomass declined as a result of the prohibition on the illicit logging of public forests and 95% of biomass was demanded by households in 2019.

The Kakamega Forest Ecosystem (KFE) is a tropical rainforest that offers a special haven for a variety of endemic insects, plants and birds. The Kenya Forest Service oversees the Kakamega Forest Reserve, Kibiri forest in Vihiga county, Yala River Nature Reserve, Isecheno Nature Reserve, Malava and Bunyala Forests, while the Kenya Wildlife Service is in charge of and the Kakamega and Kisere National Reserves (Kenya Forest Service, Kenya Forest Research Institute, Nature Kenya,Kenya Wildlife Service, Global Environment Facility and United Nations Development Programme, 2015). Kenya Wildlife Service is currently in charge of the $44Km^2$ Kakamega forest Reserve which was created in 1986, in the Northern part of the forest, currently covers and managed by. The Kenya Forest Service is in charge of managing the remaining $200Km^2$ of forest is managed by the (Tsingalia, 2020). The KFE is threatened by overharvesting of trees, exacerbated by the small size of the forest and its location in a densely populated agricultural area. Kakamega forest has a long history of logging and additional human influences like livestock grazing and firewood collection. The Bunyala Forest (BF) is a part of the larger Kakamega forest ecosystem, it covers an area of 826.6Ha (Kenya Forest Service; Nature Kenya; United Nations Development Programme; Global Environment Facility, 2015). BF is an important catchment for Lake Victoria through River Nzoia via River Lusumu. There have not been any additions or excisions to the forest. The Bunyala Forest has lower biodiversity due to high anthropogenic disturbances. The Bunyala sector is establishing plantations through the Plantation Establishment Livelihood Intervention Scheme (PELIS) with the purpose of enhancing sustainable utilization of forest resources and contribution to family livelihoods. The dominant energy source for the local farming rural communities is fuelwood which has created increased demand for fuelwood leading to fragmentation of the forest, affecting biodiversity and affecting the ability of the forest to regenerate itself. As of December 2022, 19.3% of Kakamega

County residents were using, solar and alternative energy sources is 19.3% (County Government of Kakamega, 2023). Thus, there is a need to adopt friendly, affordable household energy that will lead to health, economic and environmental benefits. While value-addition is developed in crop and animal commodities, not much has been done when it comes to energy sources. Adding value to available biomass sources will reduce pressure on available tree cover. Value addition has the ability to improve/contribute to the clean use of natural resources by opening up job opportunities along the biomass value chain

Most of the energy consumed within Kakamega County is by the residential sector, mainly through cooking in form of charcoal and firewood, the solid biomass. The notable popularity of these energy sources particularly firewood is often attributed to their cost-free availability. For instance, members of the household freely collect firewood for themselves without any cost implications. However, the heating value of such energy sources is very low. According to a study on energy saving strategies for enhanced efficiency among urban households in Kakamega, energy consumption for electricity increased with income levels (Otwori *et al*., 2019). Households in the urban area showed transition of fuels with increase in the income levels of households. Charcoal energy source had a positive correlation among the different income groups. According to Otwori *et al*., (2019), the low income groups were spending USD 10.7 monthly for charcoal, the high income group spend USD 9.5 and the middle income spent USD 8.7 per month for charcoal. As the monthly income increase, the households tend to mix the different energy sources rather than substituting other income sources as postulated by the energy ladder model. It was found that the entire income groups utilize all the sources of energy except kerosene that was not being used by the high income households. Low income households (73%) used 1-5kg of wood fuel per day while high (75%) and middle income (69%) households used 6-10 kg (Apondo , 2022) Kakamega is home to the three stone (open fire), traditional stove and improved stove. Although kerosene is a more efficient solution to firewood, its use for cooking is relatively low. The primary causes are the higher cost and availability. The adoption rate of LPG is at 0.8% (Apondo , 2022). The obstacles to that are its high cost (particularly when compared to the less expensive charcoal) and the country's constrained capacity for storage, distribution and retail. The primary cause of Kakamega's relatively high energy consumption levels in the residential sector is the daily use of inefficient technologies. In Kakamega, sugar production is the primary industry whereby factories consume electricity and cogeneration using bagasse. The transport sector uses diesel and gasoline for passenger vehicles and freight transportation. The commercial sector, community sector and public services also uses electricity for their operations.

1.2. Statement of the Problem

The increasing pressure on tree and forest cover as a result of dependence on wood fuel by households in Navakholo will affect availability and accessibility to biomass resources. On the other hand, access to cleaner alternative energy sources such as electricity and solar is costly and unattainable. There is need to enhance availability and in order to add value to the available biomass resources. In addition, an aspect hitherto unexplored is value-addition on available biomass sources. As is the case in crop and animal commodities, value addition in biomass energy can increase the shelf-life of fuel wood and its use efficiency, which together enhance its availability.

1.3. Research Questions

This study focussed on assessing changes in tree and forest cover in Navakholo Sub-County and how this has affected availability and accessibility of biomass energy sources in households. In addition to this, aspects of value addition to biomass were explored. The research questions that guided this study were as follows:

i. How has forest and tree cover in the study area changed from 1990 to 2020?
ii. How is the trend in tree and forest cover affecting availability and accessibility of biomass energy options within households?
iii. How do households and other stakeholders in the study area add value to biomass energy sources?
iv. How are the challenges and opportunities for enhanced biomass energy security addressed?

1.4. Research Objectives

The overall objective of this study was to assess availability, accessibility and value-addition of biomass energy sources within rural households in Navakholo Sub-

County, in order to contribute to policy options towards rural energy security, reduced energy footprints and increased tree and forest cover in the region. The specific objectives were:

i. To investigate trends and implications in tree and forest cover from 1990 to 2020 in Navakholo Sub-County
ii. To determine the relationship between tree and forest cover with availability and accessibility of biomass energy options at the household in the Sub-County.
iii. To examine status of value-addition in biomass energy options and consequent management practices in the sub-County
iv. To analyse challenges and opportunities of enhancing biomass energy security within households in Navakholo Sub-County.

1.5. Research Hypotheses

This study was guided by the following null hypotheses where ($p \leq 0.05$):

i. There has been no significant change in tree and forest cover in the period 1990-2020
ii. There is no relationship between the extent of tree and forest cover with availability of biomass energy options at households
iii. There is no relationship between availability of biomass energy and value-addition practices
iv. There is no relationship between socio-economic and technical factors with respect to challenges and opportunities of enhancing biomass energy security in the study area

1.6. Justification

Most rural households in Kenya rely on biomass energy and in particular firewood and crop residues for various energy uses like cooking, heating and lighting. Accessing clean energy like electricity is constrained by grid coverage and cost implications. Solar and wind power are costly and unattainable. The pressure on biomass energy will therefore continue to increase resulting into steady decline in tree and forest cover thus exacerbating impacts of global warming and climate change due to emission of carbon dioxide (CO_2).

Navakholo Sub- County was chosen due to the fact that it is located in a rural area, where there is a heavy reliance of biomass as a source of energy. The area is home to the Bunyala Forest, part of the larger Kakamega Forest Ecosystem thereby a unique case study in assessing how communities located next to forests interact with the resource. They area is highly populated and thus forms a basis of how to sustainable manage forest resources in a densely populated area. Currently demand for fuel wood surpasses supply. Thus this was a unique study to address the interplay between population growth, energy demand and deforestation.

Reliance on biomass to power domestic and agricultural functions in rural farming communities is likely to continue for a long time. Investment into guaranteed supply, longevity and effective use of biomass energy would be highly beneficial in these communities, where the cost barrier restricts access to clean energy sources like electricity. SDG no. 7, which focuses on providing everyone with affordable, dependable, modern energy, and SDG 12 on sustainable consumption and production patterns, will be realized with the help of a combination of administrative and technical innovations in sustainable energy supply and demand. (United Nations, 2015). COP 28 included a call on governments to speed up the transition away from fossil fuels to renewables such as wind and solar power (United Nations Framework Convention on Climate Change , 2024). This will be achieved through tripling of the renewable energy capacity and doubling energy efficiency requirements by 2030. It also includes a phase down of coal power and phasing out inefficient fossil fuel subsidies. Opportunities in low carbon development transitions for low and middle income countries exist in terms of providing universal access to energy (United Nations Environment Programme, 2023). The associated energy growth can be met equitably and efficiently with low carbon energy as renewables get cheaper, ensuring green jobs and cleaner air.

The demand for Kenya's energy supply will rise as a result of Vision 2030 development projects. Kenya needs to increase energy consumption efficiency and produce more energy at a lower cost. (Government of Kenya , 2007). The Energy Act further provides a structure for the effective and sustainable production, marketing, and distribution of biomass; promotes the use of fast-growing trees for establishment of commercial woodlots. It looks at improving all aspects of energy demand management and facilitating development of technologies to increase the effectiveness of energy harvesting, processing, conversion, transportation, storage, and use (Government of Kenya, 2019).

The most important source of pollution worldwide, in particular low and middle income households comes from inefficient fuel combustion from cooking, heating and lighting generating particulate matter and other noxious gases (World Health Organization , 2023). According to the WHO, almost half of the world's population live in households polluted with smoke from cooking with unclean technologies and fuels. As a result, it advocates for the implementation of clean cooking solutions within the household. The public health Act will be realised through reduced kitchen pollution. Overall, the goal of the national constitution as envisaged in article 69 on sustainable utilization, management of the environment will be advanced. Renewable energies such as biomass will be key in filling this gap thereby leading to energy security. Climate change is a major challenge as emphasis has been on the reliance on fossil fuels which are known to emit greenhouse gases leading to climate change. A shift to renewable energy, including the use of biomass will be a move in the appropriate direction trying to mitigate the impacts of climate change. Therefore, sustainable management of biomass energy would be a win for the environment and all entities dependent on it.

1.7. Conceptual Framework

According to the Millennium Ecosystem Assessment (MA), people are essential components of ecosystems and engage in dynamic interactions with other ecosystem components (World Resources Institute; UNEP; UNDP; IBRD;, 2005). The evolving state of human society is thought to both directly and indirectly drive changes in ecosystems, which in turn affects changes in human well-being. Ecosystems are influenced by numerous natural forces, while human conditions are also changed by social, economic, and cultural factors that are unrelated to ecosystems.

The interplay among determinants of household energy options can be very complex. Suffice it to note that rural households that use charcoal, wood fuel and maize cobs are logical people and make energy-based decisions based on considered factors within their livelihood domains. However, the impacts of their choices on the environment in its entirety could be both negative and positive. In this study emphasis was put on determinants of the availability, access and value-addition on biomass energy options. Household energy security (HES) was therefore the dependent variable. HES addresses challenges associated with energy access i.e. affordability, availability, quantity, proximity, reliability and cleanliness, its utility and consequences (Boateng *et al*.,2020).

At the national level emphasis is laid on energy availability, environment, energy process, governance, energy efficiency and societal effects. According to Boateng, *et al*., (2020), concepts such as the energy ladder refer change in energy use and demand patterns in accordance to variations in economic status of households. Energy stacking suggests that with increasing income, households do not switch to different fuel types but rather use an energy mix depending on the purpose of use. The Sustainable Energy Security index is used to measure HES by evaluating availability, accessibility, efficiency and environmental acceptability of energy within households (Narula & Reddy , 2016). The independent variables, intervening variables and ultimate result of balanced interventions is illustrated in figure 1.1.

Availability is the amount of energy resources required to sustain household and industry functions. It is measured by evaluating the adequacy of the energy reserves at the household. Availability at the household level is the amount of energy resources required for heating and cooking. Availability and diversity of energy options enhances household energy security. Accessibility is the time it takes for the client to reach or acquire energy services. Affordability is linked to the energy burden (energy bills as a percentage of household's income) (Brown, *et al*., 2020). Affordability can be interpreted as low energy prices for consumers. It is also related to government accounts in terms of subsidy levels and import /export balance. In relation to household income, energy costs ought to be minimal. Affordability is relative to consumer income. Energy systems are defined as energy resources, technologies, and uses connected by energy flows to support essential social functions. Energy infrastructure is categorized under these systems. Management practices involve energy efficiency and energy saving. Energy management practices are strategies aimed at reducing energy consumption, enhancing energy efficiency and promoting renewable energy use (Alhawamdeh, *et al.*, 2023)

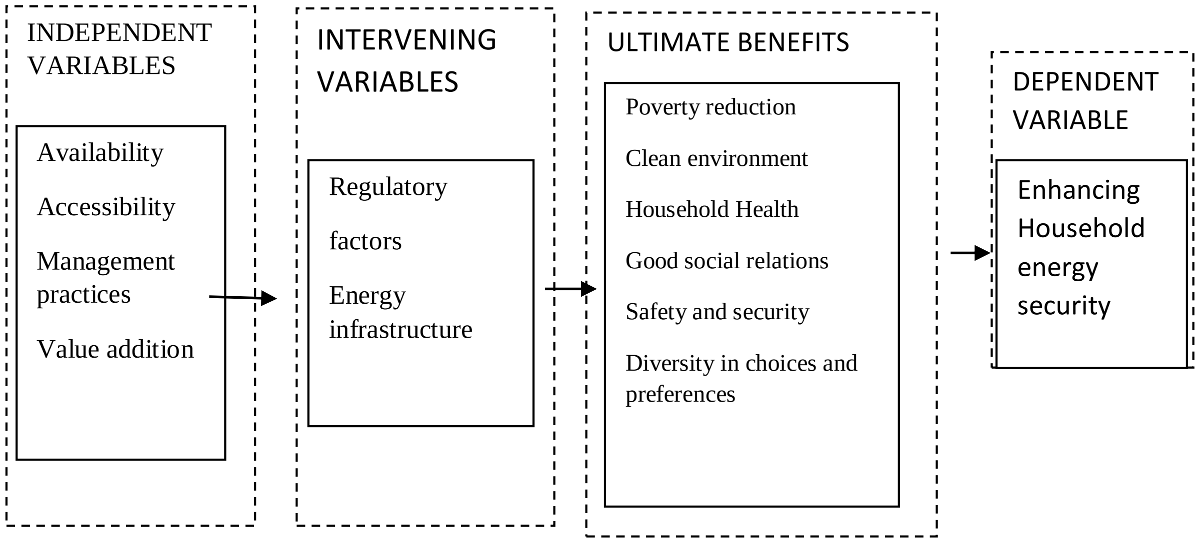

Figure 1.1 Relationship of the determinants of household biomass energy security

Accessibility in the households means how long it takes to access biomass in terms of the distance and time required. Shorter distances covered and less time spent in looking for the energy resources ensures household energy security. Purchase and affordability go hand in hand. This denotes a relationship between household income and the cost of energy service. Household should be able to afford the various energy types. In this context for example, biomass is seen as a free resource with little income allocated to purchasing biomass, making it easily available for use within households. Therefore, the more affordable the energy type, the more the households are able to access and use it thereby boosting household energy security. Energy infrastructure refers to energy resources, technologies and uses within the households. The resources include woodlots, agricultural residues, and technologies such as the cooking stoves within the household, which improve household energy security. Having adequate energy infrastructure is a solution to addressing availability, accessibility and management of energy resources within the household.

Management practices refer to energy saving practises within the household and how households can better enhance energy efficiency. It also involves management commitment, energy awareness and energy auditing. Management commitment at the household level includes decisions made by those that manage biomass in the home on energy usage that have a heavy impact on household energy security. Energy awareness involves possessing knowledge on available energy options and which options fit household needs and preferences. Energy audit takes a closer look on how to reduce the energy input in the system without affecting the output losses, wastage and enhance efficiency in household fuelwood management.

Regulatory factors include: direct tariffs, direct restrictions, deregulation, government licenses and permits (Markina, *et al*., 2020). Direct restrictions such as the ban on logging that affected supply of wood fuel. The National Energy Policy has provisions on the effective management of biomass. To enhance household energy security there is need for regulatory approaches in terms of subsidies to guarantee that households are able to access a wide range of energy options. Environmental regulations that boost businesses competitiveness and the quality of the environment without impeding economic growth can result in a win -win situation (Guo & Yuon , 2020). At the household level ultimate benefits involve modernization through the use of Improved Cook Stoves, and once people can have diverse energy options, they are able to reduce their vulnerabilities thereby contributing to household energy security. Studies on energy access, energy use and consumption, determinants of household fuel choices and efficiency in household fuelwood consumption have been done. This study will contribute to enhancing viability of the available energy options through value addition and proper management of energy resources within the household to enhance efficiency. Poor people are vulnerable to price fluctuations. Climate change and vulnerability affects energy supply. Land use changes also have an effect on the availability of biomass. Unsustainable consumption and production are putting pressure on biomass

CHAPTER TWO: LITERATURE REVIEW

2.1. Overview of Global Energy Supply and Demand Dynamics

According to a report on World Energy Scenarios for 2019, Europe has made investments in renewable energy. East Asia primarily uses coal to cater for its primary energy supply, followed by the use of oils and gas. This region is home to China, which is the biggest energy user and has 100% access to electricity. Other remaining countries in this region like South Korea, Japan meet 90% of their energy requirements through the imports of primarily coal, natural gas, and oil as fossil fuels. Energy security is a major concern due to the heavy reliance on energy imports. To keep the energy supply steady, less fossil fuels should be used, the energy mix should be more varied, and renewable energy sources should be used.

Central Asia includes India which has 78% reliance of fossil fuels that dominates primary energy supply (World Energy Council , 2019). In India, coal is the most abundant primary energy source, it is also tapping more into potential for renewable energy and favouring solar energy over coal investment. According to the WEC (2019), More than six million people do not have access to contemporary cooking fuels and technologies, so they must continue to burn fuels like wood, dung, and charcoal for heating and cooling. This makes clean cooking difficult. Asia Pacific (59%) relies mainly on oil and coal to meet their primary energy demand. Australia and Indonesia are the region's two biggest suppliers of coal. (World Energy Council , 2019). The creation of alternative energy sources continues to be a major factor in regional development. By 2035, New Zealand wants to have all of its electricity come from renewable sources, up from 85% currently. Middle East and North Africa has among the world's highest energy demands, other than China and India. The United Arab Emirates has invested heavily in renewable energy. This area mostly has oil producing countries that depend on gas and oil to meet domestic demand and earn money from exports. Latin America and the Caribbean is undergoing changes in the energy mix through the implementation of regional integration projects, structural reforms, and new energy policies. The majority of people have basic access to electricity. Hydropower consists of 50% of electricity generation though extreme whether has an impact on hydropower generation with increase and frequency of droughts. Brazil and Venezuela produce oil exports. North America has the world's most substantial fossil fuel reserves. The world's largest producer of oil is the United States. The United States has also switched from coal to natural gas to generate electricity. Reliance on wind and solar power is at 12%. The energy sector in sub-Saharan Africa is still underdeveloped in terms of availability to contemporary energy services and sustainable energy supplies. A total 890 million people cook using conventional fuels and 690 million people do not have access to electricity. (World Energy Council , 2019). The region is vulnerable to extreme weather events. There is a vast technological revolution and the majority of African nations are encouraging renewable energy, especially wind and solar power.

From the above scenarios, there seems to be a global shift from fossil fuels to renewable energy sources. Major oil producers globally are shifting to cleaner sources of fuels to enhance environmental sustainability. Europe is keen on investing in renewable energy and countries like New Zealand have turned to renewable energy for their electricity generation. Vulnerability to climate change has also affected energy supply with the increase in droughts, affecting hydropower generation. Africa seems to confront a variety of obstacles as a result of its low energy security but it is willing to invest in technologies and renewable energy in order to improve access and availability of energy. It is noted that a large number of people in Africa depend on biomass as a source of energy to cater for their energy needs. Therefore, adding value to the resource and efficiency will help in enhancing sustainability of the resource. Using biomass energy is relativity easy due to its familiarity having been transmitted from one generation to the next. Traditional stoves are preferred by end users because they are thought to be durable, easy to fuel and ideal for cooking particular foods or large quantities of food (Jewitt, Atagher, & Clifford, 2020). There have been various interventions introduced to use other alternatives but these have had varying success. The dependence on biomass is predicted to continue rising especially in developing countries (Kyayesimira & Muheirwe, 2021). To enhance sustainable biomass use, friendly interventions, energy-efficient technologies through improved cook stoves, and the use of briquettes should be introduced.

As stated in the National Energy and Petroleum Policy (2018), the most widely used biomass was fuel wood, charcoal and agricultural wastes. Agricultural residues have the potential to be highly exploited through the production of biogas. Most households have a few animals that they keep for sustenance. Among the limiting factors for biogas use are gathering sufficient water and manure. In many parts of Sub-Saharan Africa, households may have enough livestock, but the grazing nature of the animals whether free range, nomadic, semi-nomadic may make it difficult to gather enough manure to feed the digesters (Pilloni & Hamed , 2021). The challenge of biogas is the initial capital to install the facilities. There is limited technical expertise in operating and installing the facility. Households can partner to pull resources to install a biogas plant thereby reducing reliance on wood fuel. According to the IEA, (2019), there is a projected increase in the year 2040 in the use of coal (6.75 Mtoe), oil consumption (13.14Mtoe), gas (3.91Mtoe), solar (1.19 Mtoe), other low carbon (26.8Mtoe) as compared to the consumption in 2018. The use of bioenergy (9.34 Mtoe) is predicted to reduce by 2040. This shows a trend in the adoption of renewable energy sources in Kenya's energy mix. It also shows there will be less reliance on bioenergy in the energy mix, incorporating other alternative sources.

Various studies have been carried out addressing accessibility and availability of biomass in rural areas as follows. Studies carried out in Ghana show that, respectively, wood, charcoal, and gas were used by 53.5%, 30.6%, and 9.5% of households. (Twumasi , *et al.* , 2020). The rampant use of this fuel is because it is accessible, inexpensive, and there is low access to clean energy sources. Age, gender, education, occupation, and other characteristics of the household (such as size, location, wealth, income level, and health) as well as other social and environmental factors influence the choice and use of energy in a household. Households that have access to credit may be able to raise their income levels and convert from using dirty fuel to clean fuel. In Ghana, there are notable distinctions between those who use clean cooking energy and those who do not. These distinctions can be made in terms of credit received, education, household size, urbanization, off-farm employment of the household head, connections to high-ranking officials, and land access. The likelihood of using clean energy is positively and significantly influenced by credit accessibility.

Studies on household fuel preference in Kenya show that the improved stoves are in high demand, and people are willing to pay for them (Mbaka, *et al*., 2019). The presence of consumer markets structures and smoke reduction is a significant factor in the adoption of cook stoves. It is anticipated that firewood will be used even though improved models of stoves made of charcoal and ethanol will be preferred. In Tanzania, the major transition in cooking fuels is away from the primary use of firewood towards the use of charcoal (Choumart-Nkolo, *et al*., 2019). The primary industry in Madagascar is lumber, and sawdust, an organic waste product of that industry is used to make briquettes. The production of sawdust in the form of briquettes is less expensive making it a potentially viable and sustainable source of energy. It will also reduce the sawdust waste. Lack of knowledge about biomass briquettes, lack of government support, political instability, social acceptance of biomass briquettes, a preference for other types of biomass energy and fossil fuel incentives are some of the factors that affect their use. The most significant energy source is wood energy representing over 90% of the energy transition and offering jobs and livelihoods for Madagascans. Annual wood consumption is at 41.8% for firewood and 39.7 % for charcoal (Yi, *et al*., 2022).

Studies in Kenya suggest that stove adoption depends not only on demographic and socioeconomic factors (e.g., income, education), but also on geographical and environmental factors that reflect biomass availability and accessibility, and market access. A lack of financing, slow technological progress, low consumer awareness, and lack of infrastructure for fuel and stove production and distribution has hindered the promotion of cook stoves. Stove promotion and dissemination programmes tend to focus more on stove technology than on the characteristics of their target adopters. There is a large discrepancy in the local supply of and demand for fuelwood, which causes large annual wood supply variability and deficits. Stove stacking or multiple stove use is a prevailing practice in most of households in Murang’a and Kiambu. Natural barriers such as (a) the difficult landscape terrain, (b) the steep topography, and (c) climatic and seasonal variations often limit fuelwood availability and local market prices (Karanja & Gasparatos, 2020). In (Kiambu), fuelwood is mostly supplied by the local furniture and construction workshops in the form of wood-cuts; fuelwood is readily available in small, affordable quantities in the local market, and;

there is easy market access to cooking fuel alternatives such as LPG, charcoal, and kerosene, that can reduce or even substitute fuelwood for cooking. Access to credit has a significant positive effect on the adoption of improved biomass stoves. Households participating in social groups for example 'chamas' also have a significantly higher probability of adopting improved cook stoves whereby local fuelwood scarcity leads households to adopt fuelwood-saving cook stoves, compared to households in areas of abundant biomass that can be easily collected.

According to Karanja (2020), income significantly increases the probability of adopting improved biomass stoves as primary stoves. Geographical and environmental factors affect the adoption of improved biomass stoves. In particular, local biomass availability (i.e., location in the close-forest zone and semi-arid area) and accessibility (i.e., distance to fuelwood collection areas), as well as availability of other fuels (i.e., location in the peri-urban zone) seem to have a significant effect on the adoption of improved biomass stoves as the primary cooking method. Location, apart from affecting fuel and stove availability and prices, can also affect the availability of important services that can affect adoption, such as post-acquisition support (e.g., local capacity for stove repair and replacement of stove parts). Biomass accessibility seems to be an equally important factor in biomass stove adoption. That adoption increases significantly, by 4.2% ($p < 0.05$), with each additional kilometre walked from the homesteads to the most frequently used area of fuelwood collection (Karanja & Gasparatos, 2020). These studies show the factors influencing accessibility and availability of biomass, but have not addressed value addition of biomass (other than charcoal and briquettes), as biomass will remain a main source of fuel in the rural areas. Challenges in cook stove adoption has been addressed in these studies, but there is need for local based solutions to address and identify opportunities for cooking stove adoption in rural areas.

2.2. Differential Energy Accessibility and Implications for Human Well-being

Human well-being (HWB) has a variety of elements, such as the necessities for a good life, such as stable and sufficient employment, an adequate supply of food, clothing, and shelter; health and a clean physical environment, such as clean air and water; positive social relationships, such as social cohesiveness, mutual respect, and the capacity to care for others and one's own children; security, which includes safe access to resources, personal safety, and protection from both natural and man-made disasters; and freedom of choice and action, which includes the chance to accomplish what one values doing and being. In order to achieve other aspects of well-being, such as equity and fairness, freedom of choice and action is necessary (World Resources Institute, 2005). According to the conceptual framework for the Millennium Ecosystem Assessment (MA), people are essential components of ecosystems and engage in dynamic interactions with other ecosystem components. The evolving state of human society is thought to both directly and indirectly drive changes in ecosystems, which in turn affects changes in human well-being. Ecosystems are influenced by numerous natural forces, while human conditions are also changed by social, economic, and cultural factors that are unrelated to ecosystems.

Energy access will enhance basic material for a good life in terms of increased access to fuel sources thus enhancing livelihoods. This will be achieved by bridging the gap between supply and demand. Efficient and safe sources of energy will ensure that health and safety of users is taken into consideration due to less emissions. Energy access will lead to good social relations and security as competition for scarce fuel resources will be reduced, thereby leading to better living conditions. Energy access will also encourage freedom of choice due to diverse energy options available and equity and fair distribution of energy resources leading to HWB. Energy access is necessary to fulfil the Sustainable Development Goals. There is an urban rural gap in energy access particularly in developing countries. Globally, developed countries have more access to clean energy sources such as nuclear, wind and solar. However, developing countries are still lagging behind in gaining access to advanced technologies (Yao *et al*., 2020). Sub-Saharan Africa has low access to electricity, modern fuels in comparison to the rest of the world except South Africa. Furthermore, there is a high dependence on biomass. In the African context, there are better access rates in North Africa as opposed to Sub- Saharan Africa due to: limited biomass resources, favourable policy environment, climate and abundance of abundant energy resources. Low levels of energy access in Eastern Africa are because of low income levels, the nature of energy policy reform, the organization of the market, the region's vast clean energy resources not being fully developed, inadequate energy infrastructure, and a lack of investment in energy generation over an extended period of time.

Demand for wood is increasing while resources base is declining. While electrification has improved significantly in some countries, overall progress has been sluggish. The situation is particularly bad in rural areas. Kenya's rural population had a lower percentage of people with access to electricity (12.6% in 2014) than its urban population (68.4%). There is a strong correlation between household and national incomes and access to electricity. Compared to people with higher incomes, those living in poverty are more likely to be without access to electricity. In 2018, around 600 million people in Africa did not have access to electricity. Therefore, this poor electricity accessibility scenario magnifies the incidences of energy poverty in Africa (Murshed & Ozturk , 2023). Off-grid solutions, such as solar charged lanterns and small-scale solar home systems, can provide sufficient energy for improved lighting, some limited use of high-efficiency appliances and battery charging to households in rural areas. These solutions have substantially lower costs as compared to the traditional approach of expanding the national electricity grid (Sievert & Steinbucks , 2020).

Current global energy demand is concentrated in the high per-capita income, high population density areas of temperate regions, especially Western Europe, United States, Japan and China. Conversely, the tropics are home to developing economies that are poorer and consume far less energy, but whose income increase energy demand are projected to increase (van Ruijven, *et al*., 2019). Therefore, biomass availability among households is likely to decline as an effect of increasing demand for energy occasioned by increase in population. A report by the Ministry of Energy and Petroleum (2018) indicates that biomass is the main source of energy for 70% of households in the rural areas. The trend is a factor of the unfavourable rural households' economic condition and availability of firewood in such areas. Poor urban households unable to afford electricity and its facilities remain reliant on biomass energy for all cooking purposes (Tucho, *et al*., 2022). Communities living near forests have a higher advantage as they are easily able to access firewood. The national forest regulations in Kenya restrict gathering of firewood to naturally fallen branches or trunks as well as brush residues left over from harvesting timber (Njenga, *et al*., 2021). Households that have invested in woodlots within their farms have an easy option of accessing biomass, particularly wood fuel. The wood supply analysis in Kenya takes into account trees growing on farms or agricultural land, as they are a significant source of wood today and are expected to remain so in the future (Ototo & Vlosky , 2018). Availability here is in terms of accessibility and affordability. Accessibility with regards to fuelwood includes access to woodlots, forests, and markets. Energy services provide advantages related to human needs like health and life satisfaction (Kalt, *et al*., 2019). Improved livelihoods can also be achieved through savings made when households switch to modern energy sources. A household that used to rely on kerosene for its lighting, if given access to electricity can make savings on expenditure used on kerosene leading to improved livelihoods. It also includes savings on charging which the households used to pay for.

According Kyayesimira (2021) for women and their households, obtaining biomass fuel poses can be physically and psychologically traumatic. Women who gather firewood may run the risk of physical injuries and may be exposed to safety and security risks. Energy is a vital development enabler that can significantly improve men's and women's lives by increasing their effectiveness and productivity at work and at home. Enhancing energy access for women is linked to poverty reduction through time saving (replacing manual labour) and improving comfort and convenience, reducing pollution, income generating activities enhancing education and health and providing access to information and entertainment. More connections and usage may result from women having access to energy. One strategy to increase the customer base for energy services is to specifically target women. Promoting opportunities for women in the field of energy. Since the energy sector is male dominated, providing an opportunity for women in this field will enhance gender equality, income generation and empowerment. Limited access to energy services in societies and within households has an uneven impact on men and women. There is strong evidence linking women's health burdens and household energy poverty (Feenstra & Ozerol, 2021). Four million deaths from respiratory diseases occur each year as a result of exposure to smoke from inefficient cook stoves or open fires, mostly affecting women and children. Modern fuels for cooking and heating can prevent deaths and spare women and girls from physical labour, dangerous long-distance trips to gather wood, and drudgery

The residential use of solid fuels from cooking activities is attributed to household air pollution posing a significant hazard to the health of exposed populations (Sofia, *et al*., 2020). Actions to reduce energy use by households are crucial. This included the improvement of combustion efficiency of biomass fuels. Improved cook stoves can provide improved performance levels in terms of safety, pollution control, and efficiency. Energy access can be considered in relation to social context and capabilities. Social context can be divided into social conditions and social position. Social conditions involve the reasons and resources for energy poverty. This is in terms of location of households where there is limited access to modern energy services is difficult. Resources involves people's social and material circumstances including dwellings, appliance efficiency, social relations, financial resources, fair energy/fuel prices, disability or health status that can affect energy access (Middlemiss, *et al*., 2019). In the context of rural households, appliance efficiency is in terms of heating and lighting as most households use basic energy services. They also lack the financial resources to invest in modern energy sources thus increased reliance on wood fuel. Health and disability status can also affect energy status as one may be too old or physically incapable of walking long distances to access fuel wood unless they have assistance from other family members. In the context of rural households, all of them have access to biomass as their source of fuel, plant the same crops which they also use to cater for their energy needs. Roles involve the specific activities that people perform and their relation to energy poverty (e.g., tenant, employee, and parent). Gender inequalities in society may play an important role in shaping household decisions about investing in clean fuel (Chouduri & Desai, 2020). For example, a tree will be cut in the household only after the approval of the household head, mostly men. Parents also have a say in terms of use of energy in the home. They have a say on how much income will be spent on the energy resource, quantities and frequency of energy used within the household.

The Europeans recognised that achieving appropriate energy security levels was inevitable, especially with a wide range of risks for example geopolitical threats facing major producers, severe price fluctuations of energy products, supply disruptions from supplies due to political disparities as well as destructive environmental impacts (Elbassoussy, 2019). This has prompted a European declaration that seeks to increase reliance on renewable energy sources while also diversify supply sources. Poor people at the bottom of the energy ladder are vulnerable to disruptions of energy systems, be these physical and economic as reflected by price fluctuations. Energy systems of many developing countries may be burdened by disproportionate demand from the top of the energy ladder. Fuelwood production has played a key role in the nation's economic development (Audu, *et al*., 2023). Crude oil's accessibility and cost have dominated discussions about energy security (United Nations Economic Commission for Africa, 2014). Energy prices have increased as a result of a rise in the demand for energy sources. Other factors influencing energy security include political instability, market dependence and diversity of supply sources.

Access to energy is defining economic progress. This transformation is largely dependent on energy affordability, reliability and availability. The availability and affordability of electricity and clean cooking fuels is strongly related to income. Poor energy access is strongly related to income. Energy access is low in poorer countries and increases as incomes increase (Ritchie, *et al*., 2019). Energy access contributes to the growth of microenterprises contributing to employment opportunities thus contributing to poverty alleviation. There is a strong relationship between energy and economic growth, as shown by a comparison of GDP per capita and primary energy consumption. The current economic climate makes it challenging to provide services to the impoverished in developing nations. Supply-driven grid electricity, vested power dynamics that favour wealthy and urban areas, the unreliability of energy service provision, and misdirected and misappropriated subsidies are among the areas of concern. The persistent dominance of traditional unprocessed biomass in the energy mix is a challenge faced by developing countries in their energy systems (Cantarero, 2020). Supply driven grid electricity where most of those connected to electricity include places that have high population growth or where the Government can reap benefits due to the large number of voters. Due to its location, urban areas are most likely to be connected to the grid as opposed to the rural areas.

Additionally, the minimal financial cost of getting biomass facilitates its popularity among households. Cooking through firewood is often done by the traditional cook stoves (three stones), which is very cost-effective compared to other cooking appliances like electric or gas cookers. There is a close link between poverty and biomass use whereby an increase in household income raises energy poverty line (Aso, *et al*.,2023). Income has a major role to play concerning the various fuel types in use in the household. Households would like to spend the least amount of their income on fuel as there are other pressing needs. According to Mbaka (2019) depending on income level, those with higher income levels will have access to a bigger range of the energy mix, as opposed to those who cannot afford it who will depend on one particular source of energy. It is therefore important to be able to enhance livelihoods such that they can be able to diversify and use alternative fuels. There are vested power dynamics that favour cities and the wealthy. Energy Services tend to be supplied particularly to the affluent and urban areas. Power disruptions are less in these areas as there are implications on Government if this was to happen. Disruptions in supply of energy can lead to disruptions in the economy.

There is less focus on cooking programs in comparison to electrification initiatives. Rural areas rely mostly on biomass to be able to supply their energy needs. Governments tend to place emphasis on electrification as opposed to cooking programmes that receive more funding and are usually entrenched in the country's development agenda (The World Bank , 2022). Transitioning to better cooking options is not included in the grid extension and cooking fuel subsidy programs, which have had little success. Public policy is key in addressing the supply and efficiency of biomass. This is through the use of incentives to ensure that clean sustainable energy sources are appropriately priced to be able to serve the masses. Awareness creation in the role of sustainable biomass use and benefits to the environment should be highlighted. Funding should also go into research on the most sustainable biomass energy options available. Currently, the focus has been on rural electrification and solar with biomass has been marginalized. The Government, therefore, needs to invest its resources in developing the use of sustainable biomass as follows:

2.3. Biomass Energy Value Chain and Value-addition

Adding value is the process of creating a new commodity outside of the conventional framework to obtain higher returns. It is computed by subtracting the value, cost and other inputs of the raw product as compared to the processed product (Hinai & Jayasuriya , 2021). For biomass, the range of products include conventional firewood, charcoal, biogas, briquettes, sawdust, energy balls. The different actors along the value chain include: producers, distributors, consumers and retailers. Competitors to biomass include solar, gas, electricity and kerosene. Differentiated products from those offered by the competitors should be included to give biomass an edge over the competition. This can be achieved by enhancing efficiency, marketing and packaging of the biomass. Biomass is unique because of its popularity in rural areas and high demand for the product. To enhance the worth of the product there is need to focus on the unique aspects of the products, such as its availability and ease of use.

In order to add value to biomass energy, there is need to identify the customer needs and how to satisfy them. Customers want a product that is easy to use, convenient, environmentally friendly, health promoting, yet affordable. Attention should be paid to the quality, variety, packaging and technological advances of the product. Fuelwood can be improved by enhancing its efficiency through the introduction of Improved Cook Stoves, conversion to other products for example charcoal and briquettes, enhancing supply through sustainable fuel wood thus reducing the prices. Value addition can also lead to employment creation, creativity in terms of packaging and good labelling. According to Hinai (2021), value-addition enhances the objective of sustainable consumption and production of products. In this regard innovations in value-addition should start from cradle and hopefully end at the grave of the product. Industrial ecology practices are addressing these concerns in industrial products. Little has however been done in biomass energy, which explains the unsustainable demand of biomass in rural areas. The value that could be added at every phase of the life cycle of a product is the gist of this work, with respect to biomass energy. Fuel wood value chain starts from when the tree grows, cutting, drying and carbonization, packaging, transport, market and consumers. An example of wood value-chain was described by

Schure, *et al*; (2014). Conventionally value-addition can be done at each stage of the product life cycle:

2.3.1. Production of Biomass Energy at the Farm level

Biomass sources include: trees on farms, natural forest, plantations, residues from forest harvesting, salvage harvesting (sick or damages trees) and silviculture thinning, waste wood of timber operations. Production of biomass involves management of newly planted wildlings (seedlings that sprout on their own), coppices that regenerate (regrowth following tree and shrub cutting), and pollards (regrowth following tree top cutting) (Gonzalez-Garcia & Bacenetti, 2019)At the household level the collection of deadwood, dry branches, trunks are used for firewood.

2.3.2 Harvesting and Storage of Biomass

Harvesting of biomass comprises felling trees, chopping them to a manageable or desired size, drying them, and packing them for transportation. This varies based on the kind of feedstock, local conditions and intended use. It involves sophisticated techniques for harvesting wood and forest residues; extensive harvesting methods; and manual firewood collection for traditional biomass use in developing nations (World Bioenergy Association, 2022). Slash harvesting involves the removal of foliage and branches collected; residues of timber harvesting; residues from the procedure of thinning, in which some trees are chopped to make room for others to expand in diameter. A study in Myanmar showed distinct differences in fuel sources and sizes, wherein living trees provided only 16% of the firewood collected, and trees with a diameter of less than 10 cm accounted for 72%. In contrast, all trees used to make charcoal had a diameter of between 10 and 40 cm and a Diameter Breast Height of $\geq$ 15.1. cm (Protasio , *et al*., 2021). According to Njenga (2021) firewood collection involves collection of fallen wood and old, dead trees, which frequently have hollows in them, as these burn well and emit less smoke. Wood harvesting for domestic consumption was done by women who collected shrubs, tree trunks, and dry branches for firewood. It is now common for both men and women to harvest live and dead branches and trunks due to the increased commercialization of the firewood industry.

The purpose of storage is for keeping the feedstock and fuel dry and shielding it from rain and groundwater termites, theft and intruders like snakes and rats. Chopping to correct sizes, which also fit into the traditional stove and ICS with minimal Occupational Health and Safety Risk. Storage solutions consist of structures above or below ground created for the particular environment and purpose, silos, shipping containers and prefabricated structures made for a particular fuel, like pellets (World Bioenergy Association , 2019). Larger storage units are preferred which allows for purchasing of larger quantities at one occasion. Sufficient ventilation is required to prevent mould, permit more drying and reduce the amount of biomass that decomposes, as this can result in a lower energy content and prevents high temperatures creating a fire hazard. Tanks are used to store wet biomass, such as liquid biofuels and animal slurries. It is important to consider time biomass can be stored without affecting its quality. A study in South Eastern Europe that focused on the dynamics of dry storage for various firewood storage methods observed that while piles covered in plastic sheets did not exhibit any storage benefits, piles that were left uncovered and those under roofs performed similarly (Manzone, 2018). This shows that drying indoors occurs regardless of the circumstances. Outdoor drying could yield a better performance due to exposure to the elements.

2.3.3. Processing of Biomass Energy

Processing is conducted by the same personnel in production groups or specialized wood processing units. For example, for charcoal there are rural citizens who generate charcoal as a secondary product of harvested trees. Mud mound kilns are used in the domestic production of charcoal for the market. The following implements are used in the making of charcoal: axes, machetes, hoes, shovels, forks, and wooden levers. After the trees are felled, the logs are cross-cut into billets that are one to two meters long, stacked, thatched with grass, and plastered with earth, with the exception of a tiny window that is used to light a fire (Tassie, *et al*., 2021). Labour is shared during the raw material collection process, but the labour-intensive process of making charcoal is primarily performed by men (felling of trees, cross cutting, pilling and stacking of logs). According to Tassie *et al*., (2021), in Ethiopia, a careful assessment of charcoal production through the traditional techniques revealed 24% loss of timber and non- forest products. Charcoal from the kiln must be unloaded over the course of four days. Compared to fuel wood, charcoal is easier to store and transport and has a higher energy density. Most of the charcoal consumed in low-income countries is produced by low-tech kilns presenting yields of 10-22% mass (Rodrigues & Junior, 2019). Charcoal can be produced through the use of either improved (unimproved kilns, improved basic earth kiln). The use of improved technologies such as the improved *meandered* stove, *rocket* stove, *envirofit* stove (*kuni chache* stove) and (*okoa* stove) and the consequent reduction in fuel input can significantly lower the cost per meal. (Okoko, *et al.*, 2018). Increased kiln and charcoal stove efficiency directly benefits the economy because significantly less wood is needed to produce the same amount of charcoal.

By drying or densifying the pellets, pre-treatment is carried out to guarantee high standards for the fuel. This results in a higher energy content and a lower moisture content, which makes fuel storage and transportation easier. Pre-treatment and upgrading where the feedstock is either directly burned or gasified to produce heat or electricity. Drying is carried out to facilitate transport and storage of biomass energy. A higher moisture content causes the weight and volume of water to increase, which lowers the energy density (World Bioenergy Association , 2019). Higher moisture content biomass can present storage stage challenges because of increased mould growth, composting, and the accumulation of high temperatures that can cause a fire. Both passive and active drying processes are possible. The least expensive method requiring little additional equipment is passive, which involves drying without the use of an external source, such as storing feedstock in open fields. It is a slow process and requires a large storage area. In addition to this there is need to cover the feedstock and protect it from precipitation. Drying time depends on the material in terms of shape, size, density and surrounding conditions for example of air flow, storing and stacking, temperature and humidity. Active drying involves use of energy input from an external source for example a heating unit, drying of firewood by having a rafter in the kitchen and drying under the direct sun. Having adequate ventilation for airflow reduces smoke, saves fuel and decreases dangerous exposure (Njenga, *et al*., Undated)

Densifying involves additional increase of energy density and reduction of volume. Processes include: Pelletization and briquetting which entail mechanically compressing bulky biomass e.g., saw dust and agricultural residues; Torrefaction where char is created by heating biomass to 200–300°C in the absence of oxygen; Pyrolysis and hydrothermal upgrading where solid charcoal, liquid pyrolysis oil, and a product gas are produced when biomass is heated to 400° to 600°C in the absence of oxygen (Niu , et al., 2019). A study in the United States showed the use of densification of corn stover and switch grass to produce ethanol minimised supply chain costs (Albashabsheh & Stamm, 2021). Densification techniques such as balling, pelleting and pyrolysis help mitigate logistics costs associated with biomass transportation, storage and handling.

Biochar is a carbon rich solid that is created through pyrolysis from organic residue; the type of feedstock used and the pyrolysis conditions affect the productivity of biochar (Oni , Oziegbe, & Olawole , 2019). Significant progress has been made in reducing greenhouse gas emissions, decreasing soil nutrient leaching losses, sequestering atmospheric carbon into the soil, increasing agricultural productivity, reducing the bioavailability of environmental contaminants, as a result biochar is now a value-added product that supports bio-economy. Bio-economy implies the use of biotechnology to create new bio-products of economic value. Bio-char is a marketable bio-product which can be used in industries, agriculture and the energy sector. Biochar is produced from feed stocks such as agricultural wastes, animal manure and paper products. Biochar, which can be converted in through mechanical, biochemical, physical and thermochemical processes is considered a promising renewable energy source. Thermochemical conversion gives high quality product yield efficiency, breaking chemical bonds of organic matters and converts into biochar, bio-oil and syngas. The economics of producing biochar is heavily influenced by transportation. There are costs involved in producing biochar in one place and then transporting to another. The net present value of biochar increases as the number of times the mobile pyrolysis facility is dropped. The use of diary manure, wood bark, human manure, empty fruit bunches, and rice husks as feed stock for biochar had heat generation benefits. According to Oni *et al*., (2019) biochar production can be attractive if the proceeds of the sale value of $220/t for pyrolysis at 300˚C and $280/t for pyrolysis at

450°C offset the economic costs of raising, harvesting, hauling and storying the biomass feedstock, alongside pyrolysis, transportation and application of biochar. The net margin of producing biochar can be improved with cheaper feedstock a promising processing technology.

2.3.4. Transportion of Biomass

In its original form biomass is bulky increasing the costs and complexity of the transportation phase. Often, feedstock is processed e.g., wood chip, pellets to facilitate transportation. The mode of transportation depends on: type, stage in supply chain, distance, geographic and infrastructure conditions and financial means of the traders. Transport options include: Tipper trailer/truck for wood chips, pellets, agriculture and forestry by-products; Tanker for liquid fuels and rail for larger quantities of biomass. Head loading, bicycles, motorcycles, pickups, Lorries and trucks are used as a mode of transport for biomass. Traders or transporters are typically men who go to areas of production in order to gather fuel wood, or who go to a village after being contacted by production groups. Traders fill a crucial function of product collection at locations of production, coordination and financing production, transport and sales. Chopping bulky wood pieces to fit the specifications of the client or converting biomass to pellets can make it easier to transport, thereby adding value.

2.3.5. Marketing of Biomass Energy

Traders fill an important role of collecting the products at production sites, coordination and financing production, transport and sales. Wholesalers in the value chain can be categorised into two: those with their own transport and those without, who have to hire transport and prior to arranging for additional sales to be made directly or through retailers, pay a set price per truckload. Depots, direct markets, and semi-industrial consumers are the channels used to organize sales. Seasonal prices set by wholesalers that impact market dynamics and producer earnings. Retailers purchase fuelwood from wholesalers and repackage the product for sale in various neighbourhoods. Retailers set up shop at small kiosks, common markets, roadside stands in the neighbourhood, or specialty wood-fuel markets. A study in Chile showed that firewood certification programmes are likely to result in a 10% increase in the cost of firewood, and that 46% of people who are price sensitive will not pay for certified firewood, thereby limiting the implementation of the certification programme (Lavin, *et al.,* 2020). The benefits of certification include environmental, social and legal attributes are taken into consideration within the firewood supply chain.

In fuelwood marketing, a buyer and seller exchange goods at a set price so that the seller covers all costs plus the profit margin. The sources of firewood that are sold and consumed are obtained directly from farmlands or fallow lands and purchased from markets in rural areas. Firewood is easily marketed, primarily from producers to consumers (Atinga & Bannor , 2022). Fuelwood vendors often serve food vendors, restaurants, and bakeries, but the largest fuelwood consumers are hospitals, schools, prisons, and blacksmiths, among other institutions and industries. Firewood is a product that is marketed and processed with little sophistication; it reaches consumers almost directly. In both urban and rural locations, the fuelwood industry provides both temporary and permanent job opportunities, employing a large number of men, women, and children. Economically speaking, it is significant because it provides the exploiters with an instant source of income. While children and youth assisted in cutting the firewood billets to the proper sizes and loading them onto vehicles for delivery, men were responsible for harvesting and transporting the firewood to both the points of consumption and its marketing. At the subsistence level, firewood collection was done mostly by women as they tended to concentrate more on cutting and picking of fallen deadwood compared to their male counterparts, while the male dominated the large commercial firewood marketing activities that were labour intensive (Amah, *et al*.,2020).

Several prerequisites must be met for the market system to operate effectively. These include the presence and effectiveness of specific institutional and legal frameworks that protect private property, a developed infrastructure that guarantees dependable access to communication and transportation at a reasonable cost, and easy access to quality information. Among the issues with firewood marketing are the absence of standard procedures, the high expense of transportation, and storage concerns. For instance, fuelwood harvesters are forced by transportation issues to sell their goods at lower prices in rural areas rather than transporting them to metropolitan areas where the price will be significantly higher. The product's performance in the market may be impacted by this.

A trader's years of experience in the industry are important because they increase the likelihood that they will be familiar with the nuances of the industry, which may increase gross margins. Another aspect of firewood marketing is membership in the Firewood Traders Association, or lack thereof. In addition to collecting dues, mediating disputes between traders, and discouraging non-members from participating in the trade, the association's existence is important. Every business endeavour needs capital to pay for the costs of supplies, labour, equipment, land/rent, and stock. The firewood trade uses an indirect or two-level marketing channel. For instance, at the village market, urban vendors purchase in bulk or straight from the retailer, after which, then urban sellers then retail the product to households, restaurants in a format that is user-friendly for them. In the case of bulk buyers like bakeries, customers could deal directly with harvesters and cut out the intermediaries. Middlemen have an impact on the product's price. Costs associated with firewood trade include variable costs and fixed costs. According to a study by Atinga & Banor (2022) on marketing efficiency and sales outlet choice among fuelwood harvesters in Ghana, marketing costs included the cost of splitting/cutting firewood, the coast of loading/off-loading wood, the levy paid to the Municipal Assembly and the cost of transporting firewood. Poor road conditions, road inaccessibility, especially during the rainy season, and occasionally fuel scarcity are to blame for the high cost of transportation.

2.3.6. Consumption of Biomass Energy

In addition to small-scale industries, the brick industry, the agro-processing industry, and the service sector, which includes bakeries and restaurants, households are the primary users of biomass energy. Fuelwood, agricultural wastes, and cow dung are examples of naturally occurring biomass that is essential to rural households. Household factors that impact decision-making include household size, location, income, education, labour availability, fuel availability, cultural preferences, and oil prices. Direct combustion is the most widely used method of utilizing biomass.

Examples of dry (thermo-chemical) conversion processes include the gasification of forests and agricultural areas (fast pyrolysis), the production of charcoal from wood (slow pyrolysis), and direct combustion in stoves and furnaces. A significant amount of water must be mixed with the biomass in wet procedures.

There are a variety of reasons to use wood as an energy source. Many consumers base their decision on the accessibility and cost of alternative energy sources (Wassie, Rannestad , & Adaramola, 2021). The amount of firewood and charcoal used depends on the efficiency of the cook stove. Commonly found in Kakamega are the three stone stove (open fire), traditional stove, and improved stove (Apondo , 2022). The primary cause of high consumption is the application of ineffective technologies in consumer's daily activities. Wood used for household consumption is cut, split and dried. According to a study in Nigeria, each household consumed 1-5 bundles per day and a bundle is a number of tree prices of tied fuelwood weighing five kilogrammes (Abdul-Hamid, *et al*., 2020). Use of ICS remains low particularly in Kakamega County (County Government of Kakamega, 2023). A study on ICS and environmental and health outcomes in Nigeria showed that as a result the use of ICS, the users saved an average of 1.44h per day in cooking and 0.75h per day in fuel collection. The daily fuelwood savings was 1.29kg (Onyeneke , et al., 2019) Since biomass is easily obtainable as a waste product, using it as a secondary raw material for energy production in the agricultural sector is very beneficial. For instance, the installation of a biomass energy cogeneration plant for olive pomade in Italy that has environmental benefits as there are low emissions, lowers the cost of biomass disposal, lowers the cost of electricity thereby protecting from probable increases in fossil fuels and reduces operating costs (Torrisi, *et al*., 2018).

Information Communication and Technology (ICT) is used to bring energy efficiency in the home and implement green habits. Households monitor their energy usage using technology that is driven by data. To do this, it is necessary to put energy-saving measures into place and alter the mind-set of the users. Energy saving measures within the household include the use of energy saving stoves and effective fuel management. Data is used to assess energy usage and consumption trends over time, establish expectations and budgets, and measure energy efficiency (Strielkowski, *et al*., 2021).

In order to boost energy efficiency there is need to invest in clean and efficient technologies. ICT, represented by wireless mobile technologies is the link between traditional and renewable energy producers and suppliers. ICT helps to keep the environment sustainable by developing alternative energy systems. ICT solutions can lower risks, save money and ensure alignment with the SDGs. ICT also encourages refrain from climate damaging technologies. Studies by Strielkowski, *et al*. (2021) have demonstrated that when homes are updated to be more energy efficient, health care costs decrease. The foundation of energy-saving behaviour should be balanced demand-side responses, which call for the bidirectional exchange of information about energy prices and consumption. Energy users and consumers should be informed about the appropriate policies, programs, and channels available from the national government to support them in reducing their energy consumption.

2.3.7. Waste Management

Further processing at waste management stage is carried out so that nothing goes to waste. This leads to the creation of new products such as briquettes, pellets and energy balls. By briquetting, otherwise-wasted agricultural and forestry residues, charcoal—a solid fuel source high in energy is created (Dinesha, Kumar , & Rosen , 2019). Fuel that is more energy dense can be produced through briquette formation, which lowers transportation costs as compared to firewood (which is bulky and has low energy density), making the resource more competitive. When compared to raw materials briquette fuel offers better parameters, higher heating value (per volume) and lower moisture content (Ferronato, *et al*., 2022). However, because of these characteristics, high temperatures can be reached quickly resulting in less smoke and ash.

Investigations into transforming the resource into a more useful form—primarily solid briquette and fuel gas—are necessary to address the issue of inefficiency. According to Dinesha (2019) the process of gasification involves partially combusting raw solid fuel at high temperatures with steam or air to form a fuel gas (primarily CO and H_2). The technology can generate power between 3kW and 100kW using a variety of materials, including wood chips, groundnut shells, sugarcane, and biogas. To take advantage of the variety of fuel inputs and satisfy the demands of the product gas output, three different gasifier designs have been developed.

Sawdust derived from the activities of wood production is used as a source of fuel. Saw dust is burned as is in a cook stove and can also be converted into briquettes or pellets. Saw dust briquettes are made through a drying and compression process. Advantages of the briquettes compared to other biofuels are higher energy density, lower expenses for storage and transportation, as well as consistent product quality, such as a steady humidity level. When compared to charcoal particles, saw dust has a better ash content in the production of briquettes. The calorific value in briquettes made using charcoal particles (23.4MJ/kg) was higher compared to saw dust (19.7MJ/kg) (Ajimotokan , *et al*., 2019). . Energy balls are also made from waste material such as sawdust, ash, agricultural residue to provide a source of energy within the household.

2.4. Research Gaps

The foregoing literature review has explored availability, accessibility and status of value addition in biomass. The most widely used biomass are fuelwood, charcoal and agricultural wastes. Large discrepancies in the supply and demand of fuelwood causes large wood supply variability and deficits. Natural barriers such as difficult terrain, topography, climatic and seasonal variations often limit fuelwood availability. Biomass availability among households is likely to decline as an effect of increasing demand for energy occasioned by an increase in population. Age, gender, education, household size, location, wealth, income level and health, social and environmental factors influence the choice and use of energy in a household. Access to credit may raise income levels and convert from using dry fuel to clean fuel.

The range of biomass products and actors form part of the value chain. Differentiated products from the competitors can be achieved by enhancing efficiency, marketing and the packaging of the biomass. Fuelwood value addition starts from tree growing which involves coppicing and pollarding; processing involves charcoal production, drying, densification, pelletization, torrefaction and briquetting; transportation, marketing (traders, wholesalers, retailers); consumption by direct consumption, wood is cut, split and dried.

Essentially the focus in policy and practice in Kenya has been on rural electrification and to some extent micro-solar systems. The use of biomass has been largely marginalised. Based on the above review of literature, the following research gaps still merit attention in pursuit of energy security within rural agro-ecosystems.

i. The need to sustain adequate supply of biomass energy within households against declining land area available for agricultural use as shown in section 2.2.
ii. The need to diversify into alternative clean energy sources as shown in section 2.2.
iii. The need to address unsustainable consumption and production of biomass as shown in section 2.3.6.
iv. The need to add value on biomass energy along its value-chain as shown in section 2.3.

CHAPTER THREE: METHODOLOGY

3.1. Study Area Characteristics

3.1.1. Location

This study was done in Navakholo Sub-County in Kakamega County. The Sub-County is located between longitude 34.35 and 34.45 degrees East and latitude 0.17 and 0.29 degrees North and covers about 259 km^2 (Figure 3.1). Navakholo Sub-County's estimated population based on the 2019 national census is 153,977 (KNBS, 2019).

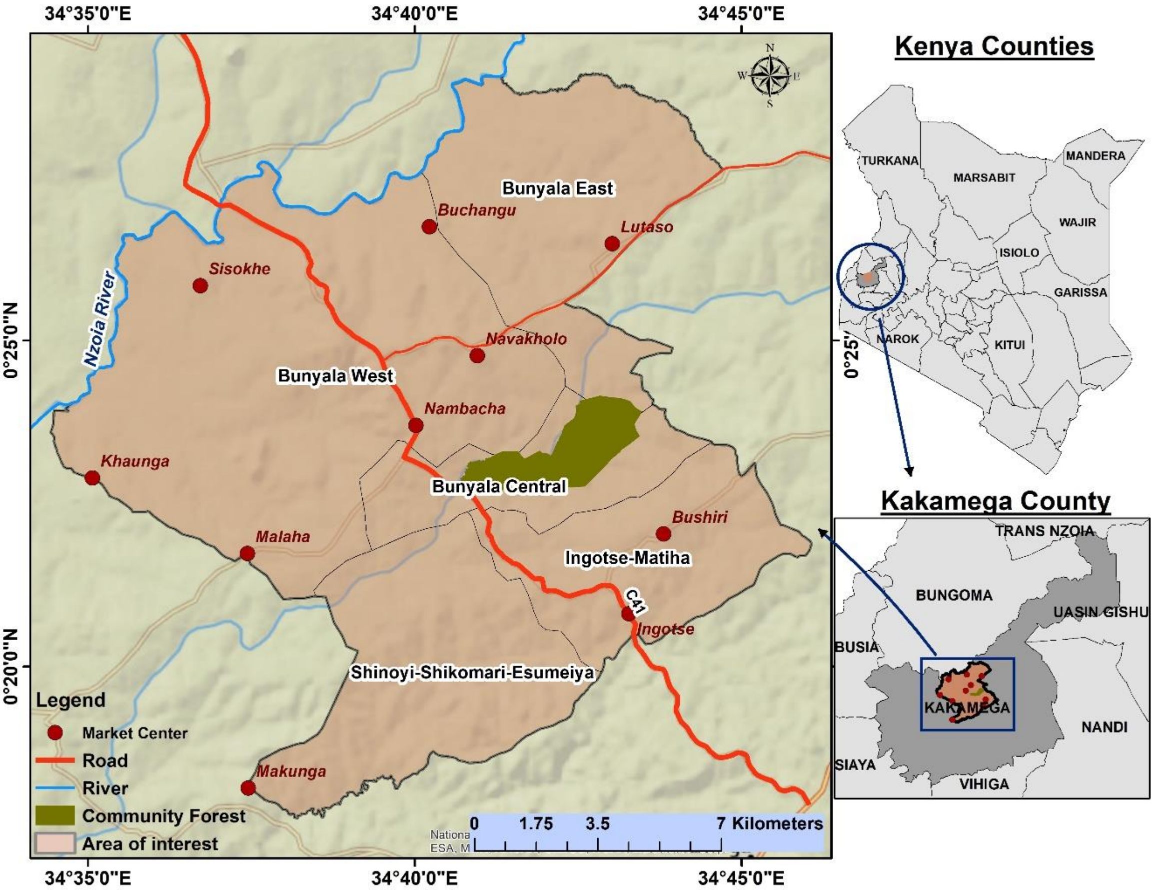

Figure 3.1: Location of Navakholo Sub-County (Source: Researcher: KU-GIS LAB 2023, Data source: ESRI Africa Geoportal)

The Sub-county has 5 Wards: Shinoyi-Shikomari-Esumeiya, Ingotse-Matiha, Bunyala Central, Bunyala East, and Bunyala West. The popularly grown food crops in the area are cassava, beans, sorghum, and maize. The significant decline in the area's tree cover and agrobiodiversity is greatly attributable to the past increased involvement in sugarcane farming. The surveyed households are indicated in figure 3.2 below.

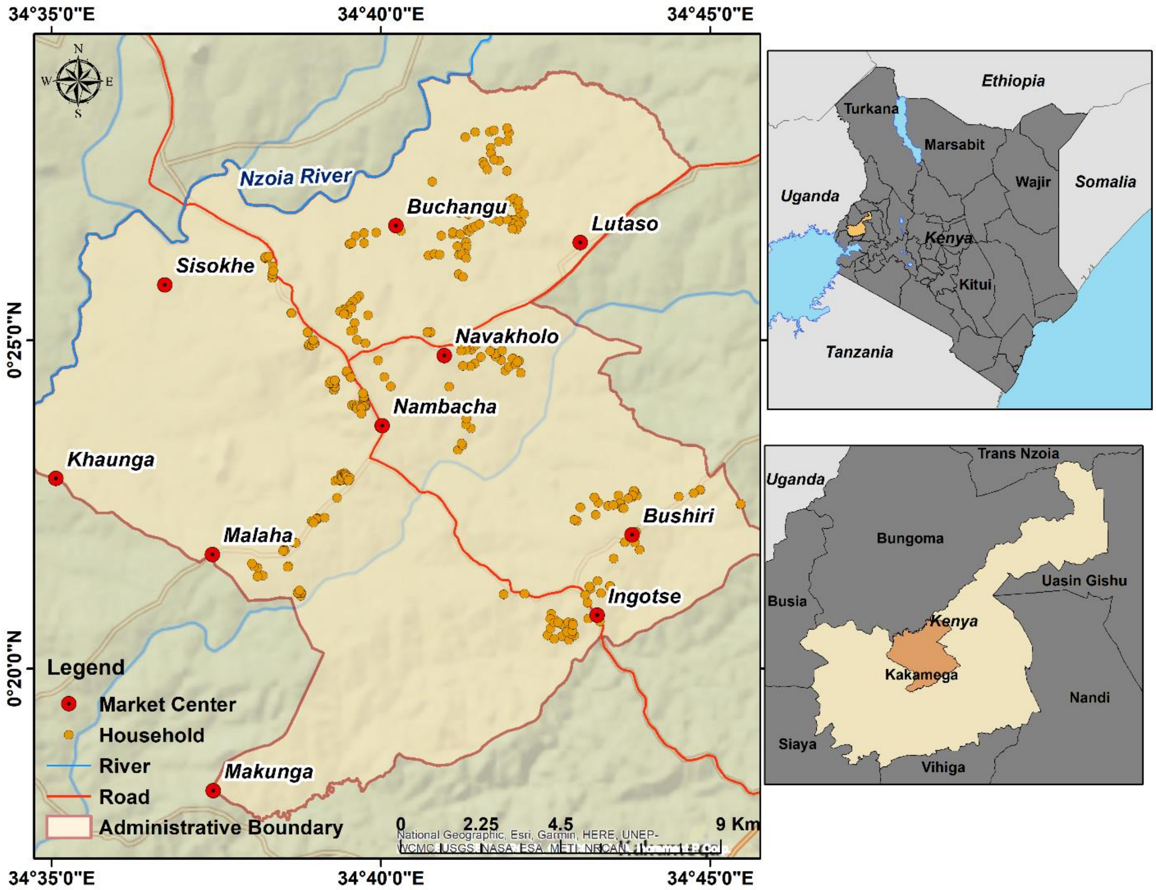

Figure 3.2: Location of households surveyed in Navakholo Sub County

3.1.2. Climate and Ecological Zones

Annual rainfall ranges from 1280mm to 2214mm. There is a high expectation for rainfall, with at least 500–1100 mm expected in the first rainy season and 450–850 mm in the second. It begins at the end of July and ends abruptly in November. While December and February experience light rain, March and July experience heavy rain. The range of temperatures is 18°C to 29°C. Kakamega County has an average humidity of 67%. Due to the humid climate, annual evapotranspiration is only 1600–1800 mm. Kakamega County is therefore classified as being in the agro ecological zone Upper Medium and Lower Medium zones (Ministry of Agriculture , 2005). The soils in Navakholo consists of upland soils- fertility is generally low and needs to be heavily manured and fertilized seasonally. The area is in the Lower Middle-Level Uplands (slopes between 2 and 8%, altitudes between 1200 and 2200 masl, gently undulating to undulating). Its soils are categorised as soil description (UmG3) consisting of ferralo-orthic/chromic acrisols: well-drained, reddish-brown, friable sandy clay to clay, deep to very deep (Jaetzold , Schmidt, Hornetz, & Shisanya, 2007). Navakholo is under the AEZ LM1 (the majority) and LM2 agro ecological zones. LM Lower Midland Zones LM 1 sub zone p or two refers to Lower Midland Sugar Cane Zone with two cropping seasons can be divided into permanent cropping possibilities. LM 2 refers to Marginal Sugar Cane Zone with a long cropping season, medium-to-short cropping season, and intermediate rainy season. The Agro ecological Zones (AEZs) LM 1 and LM 2 are suitable for sugar cane, dairy, tea and coffee production.

3.1.3. Population and Land Use

The 2019 census estimated the population of Kakamega County at 1,867,579, which translates into a population density of 619 persons per square kilometre (KNBS, 2019). With a population density of 597persons per square kilometer in Navakholo sub-county, pressure on land in the region will keep increasing posing serious risks like land degradation, loss of tree and forest cover and ultimate exacerbated human ill-being. Household farm sizes range from 0.4 ha to 1.2 ha. As such land use in this county is dominated with small scale subsistence farming focusing on maize and beans and other crops like sweet potatoes, bananas and cassava among others. Sugarcane is the main cash crop grown and lately a key contributor to declining land under food crops. While these crops suit the region based on its agro-ecological zonation (Jaetzold, *et al*. 2007), sustainable intensification and diversification of livelihoods is what will keep households on a trajectory of food and income security (Waswa, *et al*., 2012) and environmental resilience.

The natural gazetted forest area is 244.25km^2 while non-gazetted forest cover is 26.5Km^2 (County Government of Kakamega, 2023). The natural forest consists of the Kakamega Forest reserve, Kibiri Forest, Malava Forest and Bunyala Forest (Kenya Forest Service; Government of Kenya; Nature Kenya ; Kenya Wildlife Service; Global Environment Facility ; United Nations Development Programme;, 2015). It can be assumed that without consistent surveillance and enforcement of forest conservation regulations, this natural ecosystem will remain at risk of encroachment and its negative impacts in response to population pressure.

3.2. Research Design

The study adopted a mixed methods research design. This is an approach to inquiry that combines both qualitative and quantitative approaches. It is also called mixed methods research design (Bentahar & Cameron , 2015; Mutuku, 2020). The qualitative approaches focused on spatial analysis of land use land cover changes. The qualitative approach entailed use of social surveys to gather data from land users on various responses around land use land cover changes and in particular how they influence availability and access of biomass energy.

3.3. Target Population, Sampling Procedure and Sample size

The target population was all the 32, 315 households in Navakholo Sub-County based on the 2019 population census (Government of Kenya, 2019). The sample size was calculated by use of the formula described by Yamane (1967), based on 95% confidence interval thus:

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

Where n is the sample size, N is the population size and e is the level of precision. Accordingly, the design sample size was as shown below.

$$n = \frac{32315}{1+32315(0.05)^2} = 395$$

This design sample size (395 households) was proportionally distributed to the wards as shown in Table 3.1. Individual households in the wards were then selected through systematic random sampling.

Table 3.1: Distribution of respondents in wards in Navakholo sub- County

Ward Name	*Population*	*Area in km²*	*Weighted population ratio*	*Percentage of Respondents*	*Proportionate sample size*
Ingotse-matiha	22,091	34.4	1	16.1	52
Shinoyi-shikomari-esumeiya	25,352	48.4	1.4	18.5	74
Bunyala west	38,407	73.3	2.1	28	111
Bunyala east	22,122	45.1	1.3	16.1	68
Bunyala central	29,193	56.8	1.7	21.3	90
Total	**137165**	**228**	**7.5**	**100**	**395**

Source: Researcher and (County Government of Kakamega, 2016)

Key informants purposively sampled were also a critical source of data, especially during the focus group discussions as detailed in section 3.4. below.

3.4. Data Collection Methods

3.4.1. Spatial Data

Standard Geographical Information System (GIS) procedures were used to map out the study area, and to assess land use and cover trends from 1990-2020. Satellite images covering the years 1990, 1995, 2000, 2005, 2010, 2015 and 2020 were obtained from Landsat 8, 7 and 1-5. This was done through ground survey where GPS coordinates were recorded and photographs taken. Secondary GIS data was used from ESRI Africa Geoportal. Satellite images were processed and classified. These images were then subjected to accuracy assessment using sentinel and google earth to produce the land cover maps.

3.4.2. Questionnaire-based Survey

Social data was collected using questionnaires to assess socio-economic aspects, access, utilization and value addition of biomass within the household (Appendix 7.1). Data was collected from selected individuals within the household. This included women particularly because they interact more with the biomass as they are heavily involved in carrying out domestic chores such as cooking within the household. The questionnaire was structured into five sections as follows: socio-economic data which covered the Wards in Navakholo Sub-County, location, sex, age of the respondents, household size and income range of the respondents. Section B on status of biomass energy options in the household covered tree cover trends, type of fuels used, adequacy of fuel wood supply, sources of biomass energy, distance, frequency, dangers of fuelwood collection and fuelwood shortage. Section C covered adoption of the Improved Cook Stove. Section D on effects of management regimes on household energy, the adequacy of wood fuel, relevance and characteristics of tree species in the household. Section E covered challenges and opportunities in the uptake of biomass energy and adoption of alternative energy sources.

3.4.3. Biomass Value Addition Survey

Data was collected using the tool described in Appendix 4 to identify value addition and management practices among stakeholders within the biomass value chain. These stakeholders included producers, distributors and retailers of biomass. Markets were chosen according to market days within the sub-county. Five markets were selected, namely: Nambacha, Makunga, Malaha, Bushiri and Kakamega. In each market six vendors were randomly interviewed based on the value addition tool. Though not currently in Navakholo Sub-County, Kakamega market was chosen due to its strategic and unique position as having the biggest market day in the county.

3.4.4. Key Informant Interviews and Focus Group Discussions

The interview schedule for the key informants covered availability, access and utilization of biomass energy within the county (Appendix 7.5). Key informants included Ward administrators, community leaders, County NEMA Officer and Bunyala Forest Warden KFS. The Focus Group Discussions (Appendix 2) targeted a minimum of 10 people in each ward composed of men, women and youth to get a unique perspective of their interaction with biomass (Table 3.2)

Table 3.2 : Composition of FGD participants

Ward	**N**	**Gender**		**Occupation**					
		F	**M**	**Employed**	**Farmer**	**Business**	**Student**	**CHV**	**Clergy**
Bunyala Central	10	5	5	2	1		4	3	
Bunyala West	13	9	4	2	4	3		4	
Bunyala East	16	8	8	6	6		3	1	
Ingotse Matiha	10	7	3	3	3		2		2
Shinoyi-Shikomari-Esumeiya	10	8	2		8	2			

*****n= sample size; CHV- Community Health Volunteer (Source: Researcher, August, 2020

In terms of energy use efficiency, a total of thirty key stakeholders in the biomass value chain were selected to give information on the status of value addition. Six biomass vendors were visited and interviewed on the marketing days of Nambacha, Makunga, Malaha, Bushiri and Kakamega.

3.4.5. Environmental Check Lists

An environmental check list was used to document household tree coverage and pattern, tree species, biomass use, value-addition practices and managerial practices around biomass energy options (Appendix3).

3.5. Data Analysis

3.5.1. Spatial Data

The boundary of the study area was extracted from the Kenya administrative boundary mother dataset and corroborated with GPS coordinates collected during field visits in the study area. Key features such as market centres, schools, community forests were digitized on-screen using a high-resolution satellite image. Multispectral satellite images were accessed from the data repository maintained by the United States

Geological Survey (USGS), accessible at https://earthexplorer.usgs.gov/. The output was maps showing changes in land use from 2000 to date and availability of forest cover. Trend analysis of land use and forest cover was done based on standard GIS procedures as summarised in Figure 3.2.

The image classification process entailed extracting land use classes from a composited multiband raster image using both supervised and unsupervised image classification techniques in Erdas Imagine. Given the spatial and spectral resolution of satellite images from the Landsat mission, three broad land cover classes were developed to guide the analysis process. The land cover classes comprised the following:

i. Crop land class comprised of all the activities from small to large scale agricultural activities. It included the small-scale subsistence farming, plantations, and grasslands.
ii. Wood land class was made up of land covered with trees from low density to medium density such that the undergrowth receives sunlight.
iii. Settlement and others included all the land covered by residential infrastructure and homesteads, transportation networks, markets and shopping centres, schools, and bare grounds.

Accuracy Assessment of Satellite Images

The main goal of the accuracy assessment process was to compare the classified images to sampled images of a higher resolution and substantiate with information on the ground. In this case, high resolution imagery was sampled from Google Earth and analysed visually to draw a comparison. Ground truthing of satellite images was done in nine sites thus: Ingotse secondary school, Navakholo Primary school; Navakholo, Khaunga, Makunga markets; Navakholo forest office and forest boundary; and sub-county boundary in Lutaso, Bunyala East and Shinoyi-Shikomari and Esumeiya wards. GPS coordinates for Ground Control Points (GCPs) were established to guide the visual interpretation and comparison of the images. Time series analysis was done on the land use and forest cover trends from year 1990 to 2020. The Autoregressive

Integrated Moving Average was used to model land use trends and predict future trends.

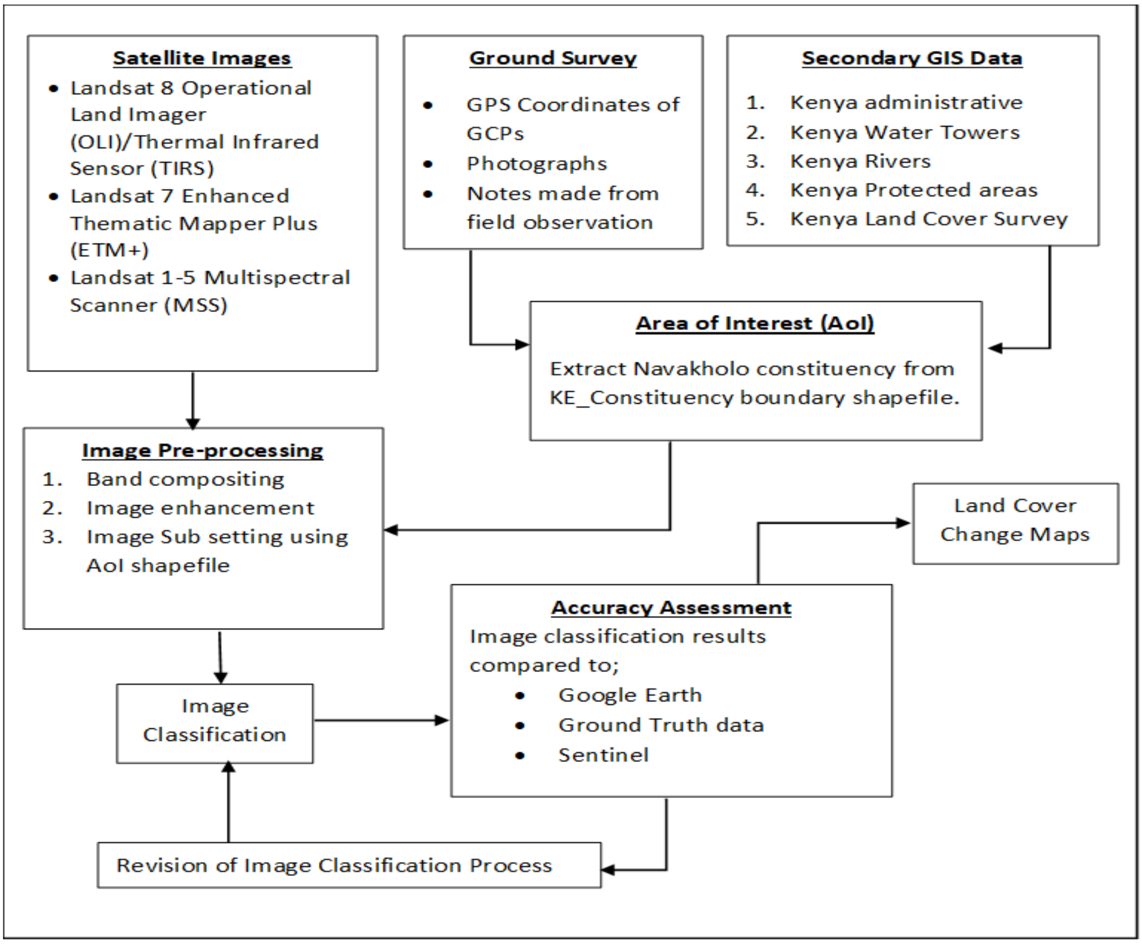

Figure 3.3 Flow chart of geo-spatial techniques used to analyse satellite images.

3.5.2. Questionnaire Data

Questionnaire data were analysed for descriptive and inferential statistical analysis. Descriptive statistics helps to describe, show or summarise data in a meaningful manner in the form of frequency, standard deviation and means. It was used to analyse socio- economic characteristics of the households in the study area. The direction and strength of the linear association between two variables were measured using correlation analysis. There can be a positive or negative correlation between the two variables for example the association between tree cover and adequacy of biomass energy. A cross tabulation is a two-dimensional table that shows the proportion of respondents who meet predetermined criteria as indicated by the table's cells. It offers details regarding how the variables relate to one another for example tree cover and adequacy of biomass energy. Chi square compares two variables in a contingency table and is used to determine the cross-tabulation table's statistical significance. It compares two sets of data to see if there is a relationship. A small p value (under 5%) usually indicates that a difference is significant. Chi square statistics have been done to test relationships between tree cover and biomass usage. Regression analysis estimates the relationship between two or more variables and the predicting dependent. The linear regression model determines a deterministic relationship between the dependent variable and the independent variables (Greene, 2002).

To model adequacy of tree cover and preference of energy types in the households, stepwise regression analysis was used. The model equation is represented as: $Y = \text{constant} + \beta_1 X_1 + \beta_2 X_2 + \varepsilon$. β_1, β_2 are regression coefficients that represent the contributions made by the various energy types. Positive regression coefficients mean there will be a corresponding increase in occurrence each time explanatory variables add a unit of value; on the contrary, when regression coefficients are negative, there will be a corresponding reduction in occurrence each time explanatory variable add a unit value (Zhao, Zhao, Jiang, & Xue, 2018)

3.5.3. Biomass Value Addition

Data from this tool was entered into Excel where descriptive and inferential statistics using correlations were presented. Descriptive statistics were used to analyse the data for example biomass usage among vendors. Correlations were used to assess relationships between biomass management and type of biomass used.

3.5.4. Key Informant Interviews and Focus Group Discussion

Data gathered from key informants subjected to in-depth content analysis and presented in a suitable narrative to support the discussion of results from other tools. FGD data was similarly thematised and subjected to content analysis and presented as narratives to support discussion from questionnaire data.

3.5. Reliability and Validity of Data

This was done through pre-testing of questionnaires and making necessary adjustments. Pre- testing was done by sampling ten households in the study area before the data collection survey, checking for errors and compatibility with prevailing local conditions. Data was collected only by trained research assistants. Quality control was done daily on every completed data and only well-completed questionnaires admitted for analysis.

3.6. Ethical Considerations

This research was implemented in strict conformity with the research ethics provided by NACOSTI. Guidelines for the use of social survey tools were adhered to. A permit was obtained for this research (Appendix 7.6)

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents analysed data and discusses its implications on policy and practice in biomass energy solutions. The discussion is sequenced based on the four specific objectives that guided this study.

4.2 Demographic information of the sampled respondents

Sampled respondents were adults of ages between 18 to 95 years. The mean age was 40.6 year. Female respondent accounted for 66.5% and male 33.5%. The average household size was 6 members. Majority of respondents (53%) had primary education. Approximately (73%) had a monthly income of less than KES income 10000 (Table 4.1). The implications of such basic education and income insecurity on energy use cannot be overemphasised. Farming was the main source of income, again indicating the potential sustained pressure on land cover.

Table 4.1: Socio-economic Information of respondents

Education level	**Frequency**	**% F**
Non-formal	27	6.9
Primary	209	53.0
Secondary	111	28.2
Tertiary	46	11.7
No response	1	0.3
Sources of income	**Frequency**	**% F**
Farming	218	56.3
Casual labour	46	11.7
Business	37	9.4
Formal employment	30	7.6
Other sources*	61	15

* included informal employment and businesses, which do not guarantee income security (N = 394)

4.3. Trends in Tree and Forest Cover from 1990-2020

The year 1990 served as a baseline year from which land cover changes were measured. Area computation shows that 5690 hectares was covered by woodland vegetation. (Figure 4.1). There was a net decline in area covered by crop land and woodland but an increase in area covered by settlements from 1995 to 2000 (Figure 4.1-4.3; Table 4.2). This was attributed to increasing demand for wood fuel commensurate with increasing population and more demand for housing. On the other hand, tree cover in protected areas (Bunyala Forest) appears to have increased during the same period, thus indicating positive gains in forest recovery efforts by the authorities. Allowing only grazing and not the shamba system must have played some positive role in this regard.

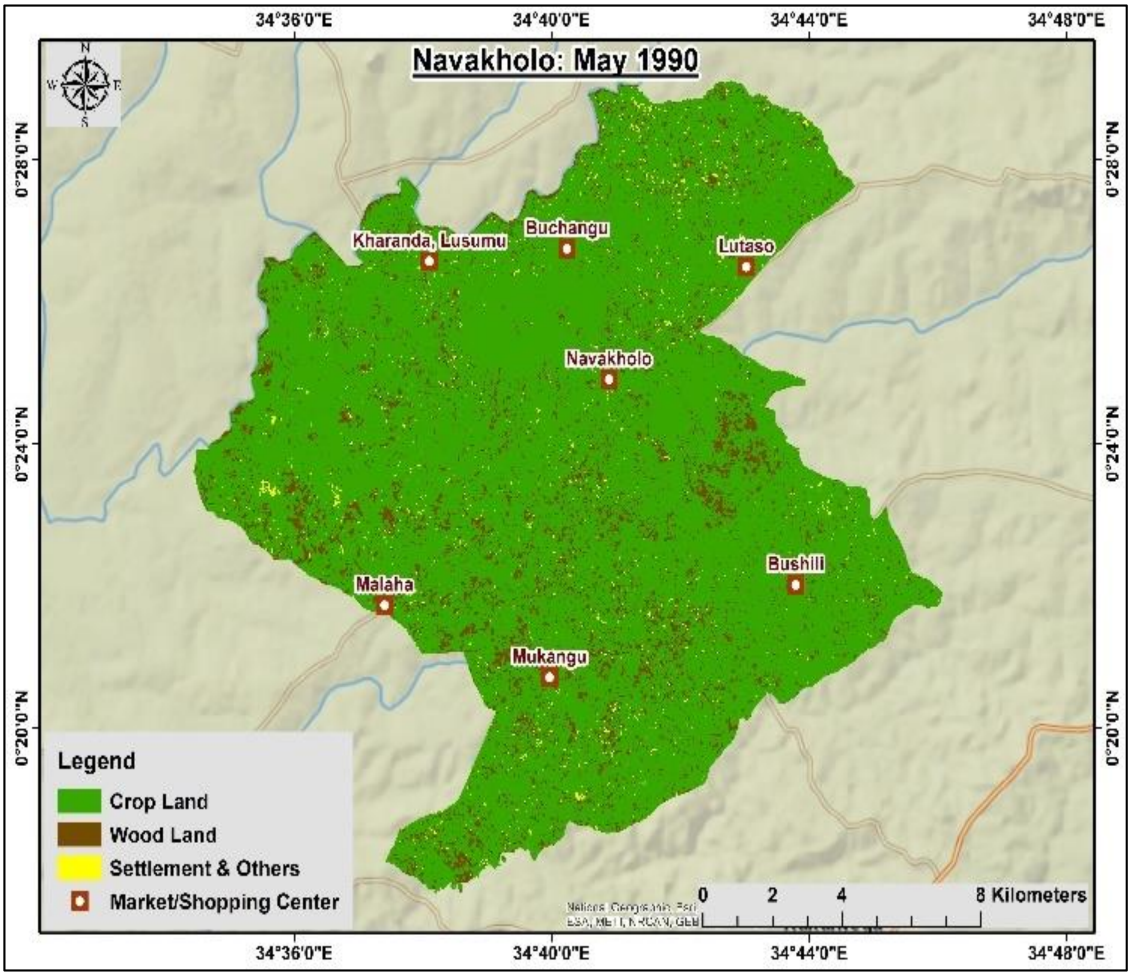

Figure 4.1: Land Cover in Navakholo May 1990

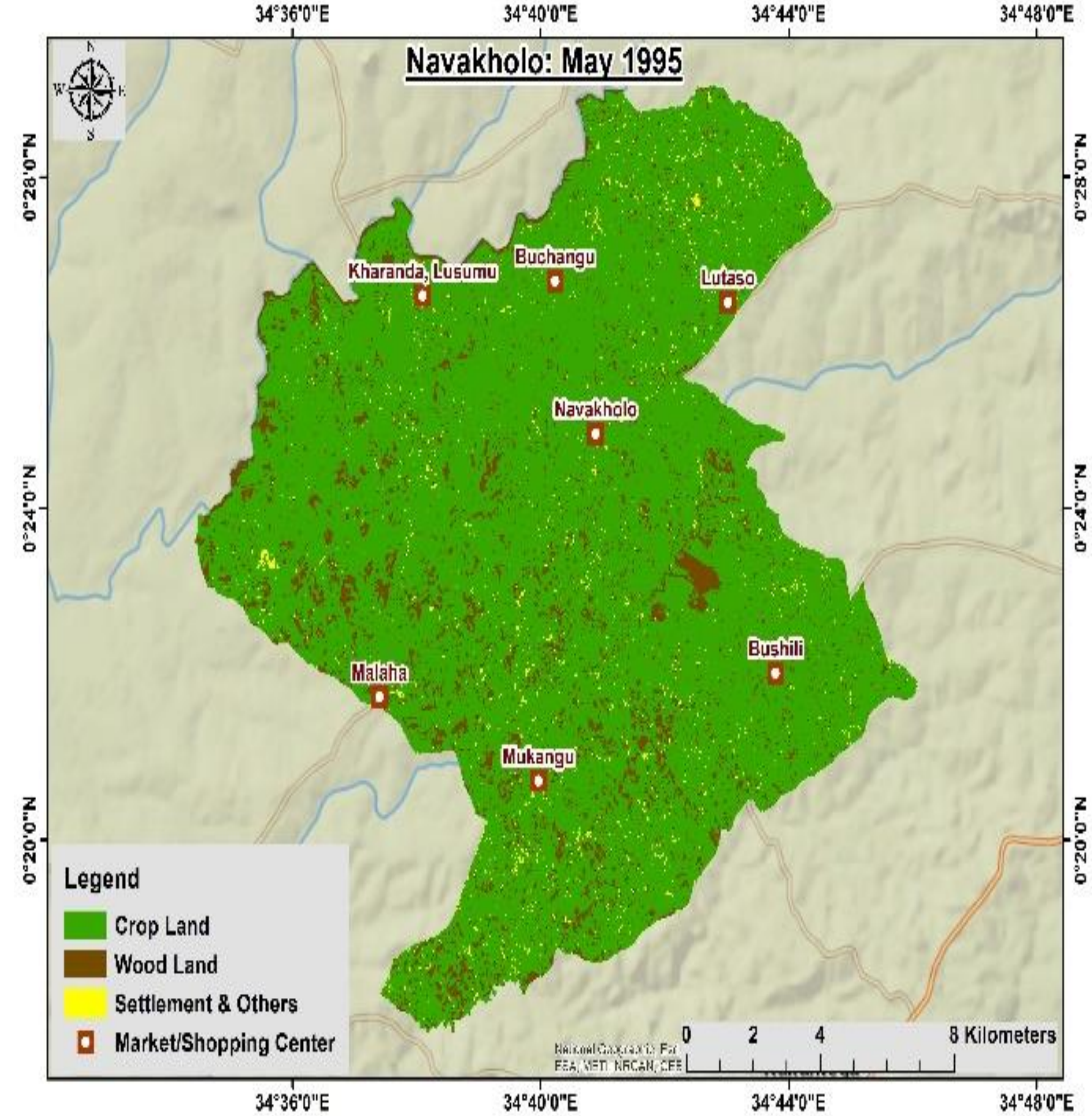

Figure 4.2: Land Cover in Navakholo May 1995

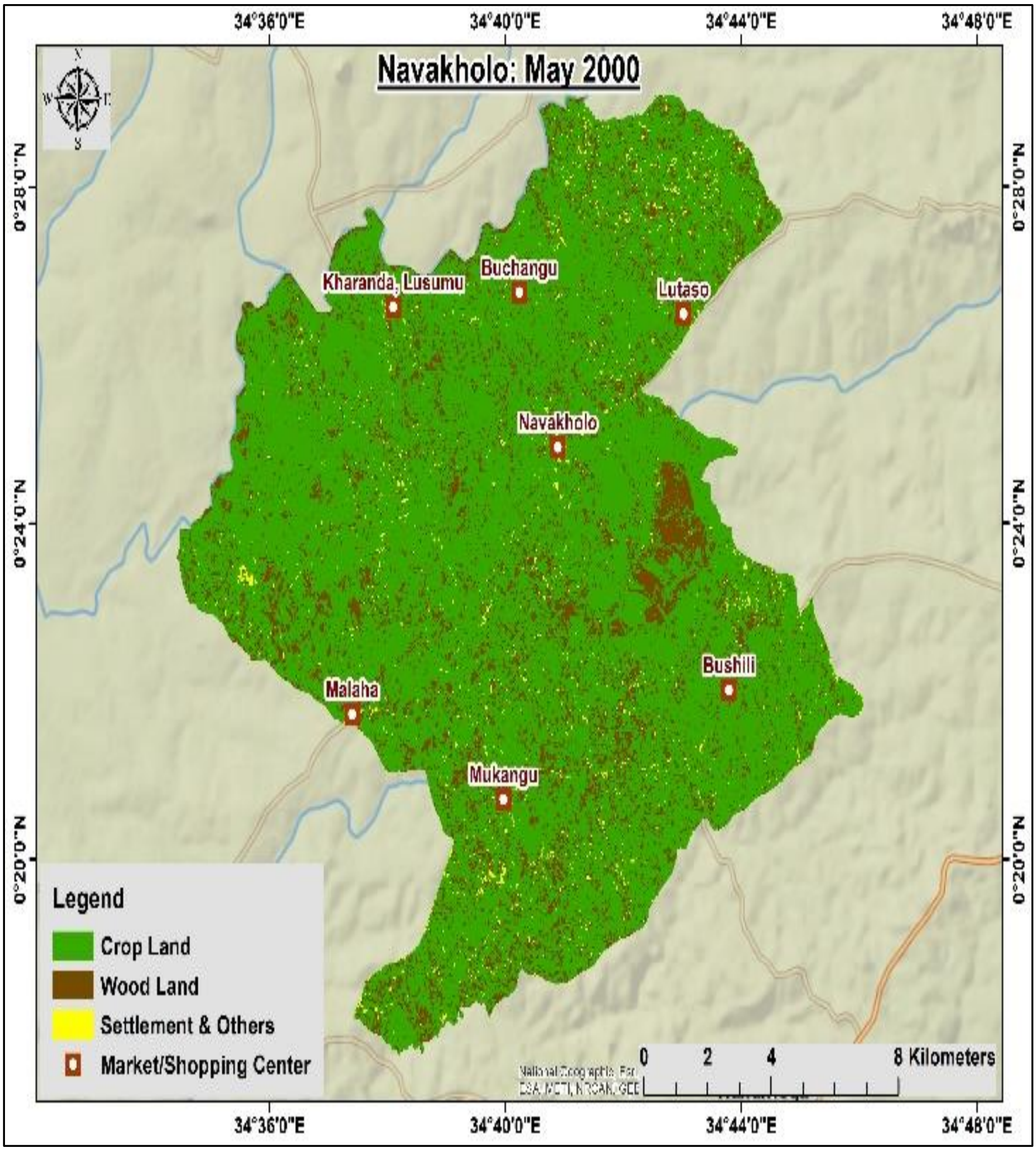

Figure 4.3: Land Cover in Navakholo May 2000

Table 4.2: Trends in land use changes from (1990-2000) in hectares

	1990	**1995**	**2000**	**Net Change**
Cropland	19,514	19,518	19,450	-64
Woodland	5,690	5,196	5,013	-677
Settlement and other land uses	696	1,187	1,437	741

The year 2005 to 2015 registered a decline in cropland but an increase in woodland and settlement for the same reasons attributed to 1995-2000 (Figure 4.4-4.6 and Table 4.3). Increasing population is causing unprecedented demand for housing and hence subdivision of land to accommodate emerging families, as dictated by cultural norms on ancestral land. The increase in built area is also attributed to an increase in common utilities like roads and schools. The reduction in crop land should nevertheless worry policy makers when it comes to food security planning.

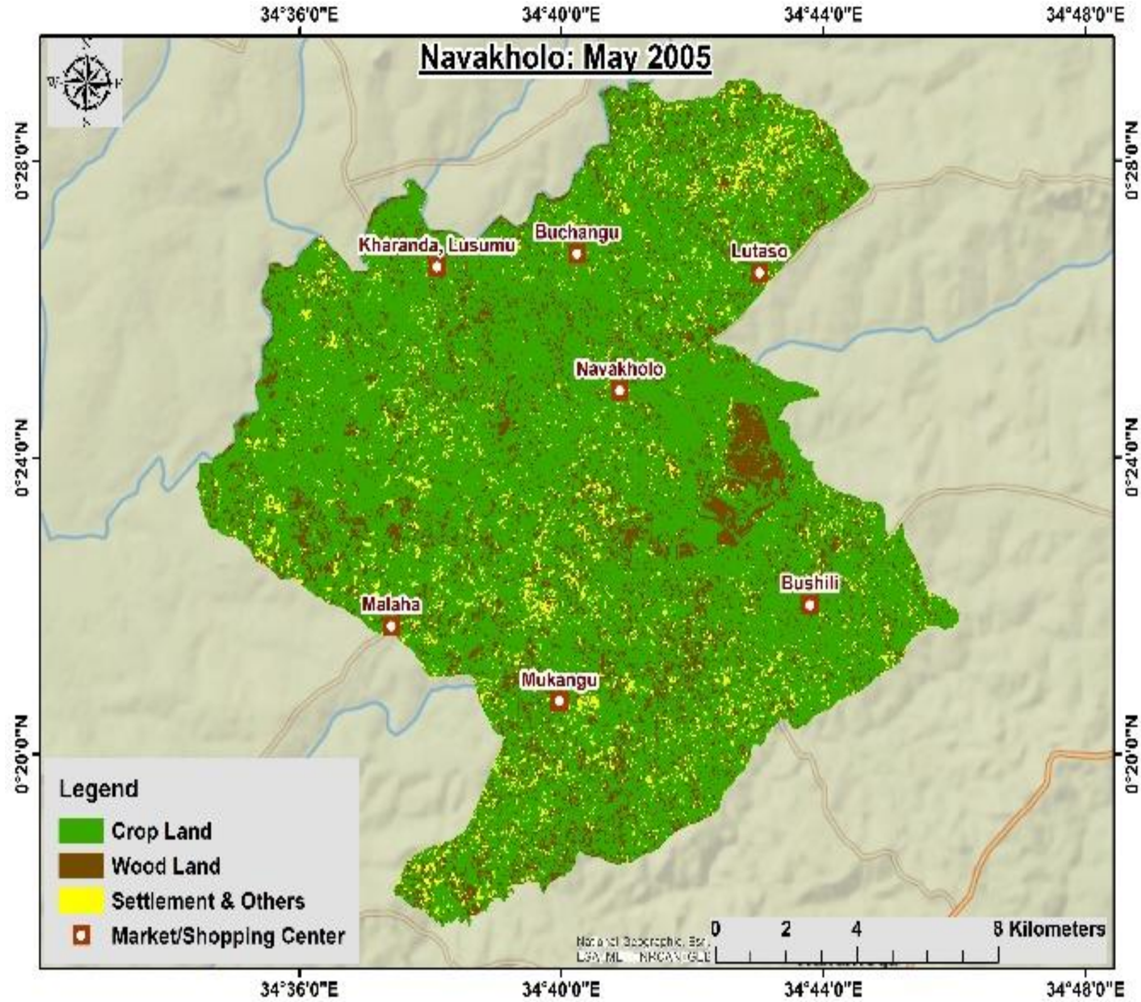

Figure 4.4: Land Cover in Navakholo 2005

Source: (Researcher: KU-GIS LAB 2023, Data source: ESRI Africa Geoportal)

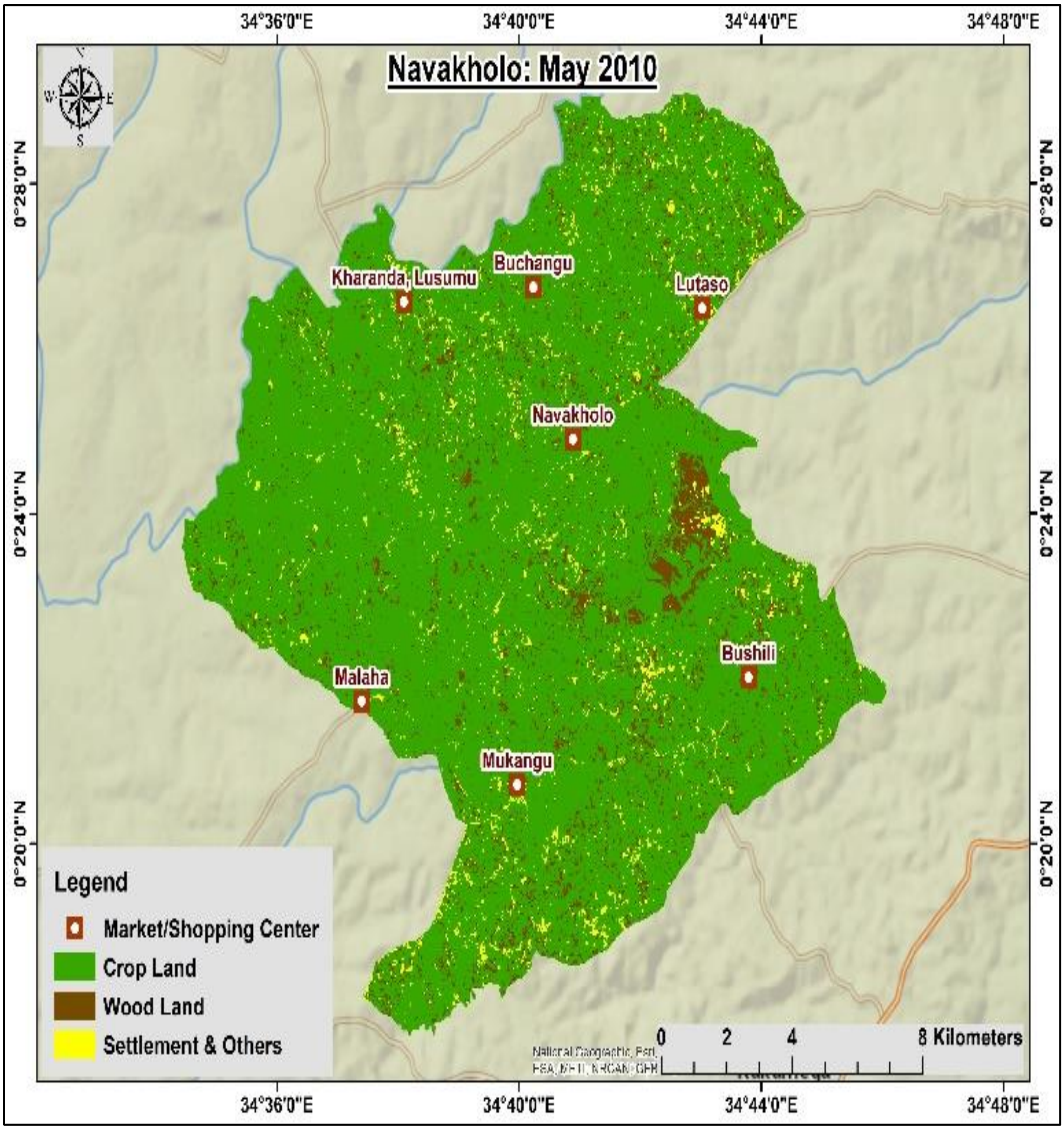

Figure 4.5: Land Cover Navakholo May 2010

(Source: Researcher: KU-GIS LAB 2023, Data source: ESRI Africa Geoportal)

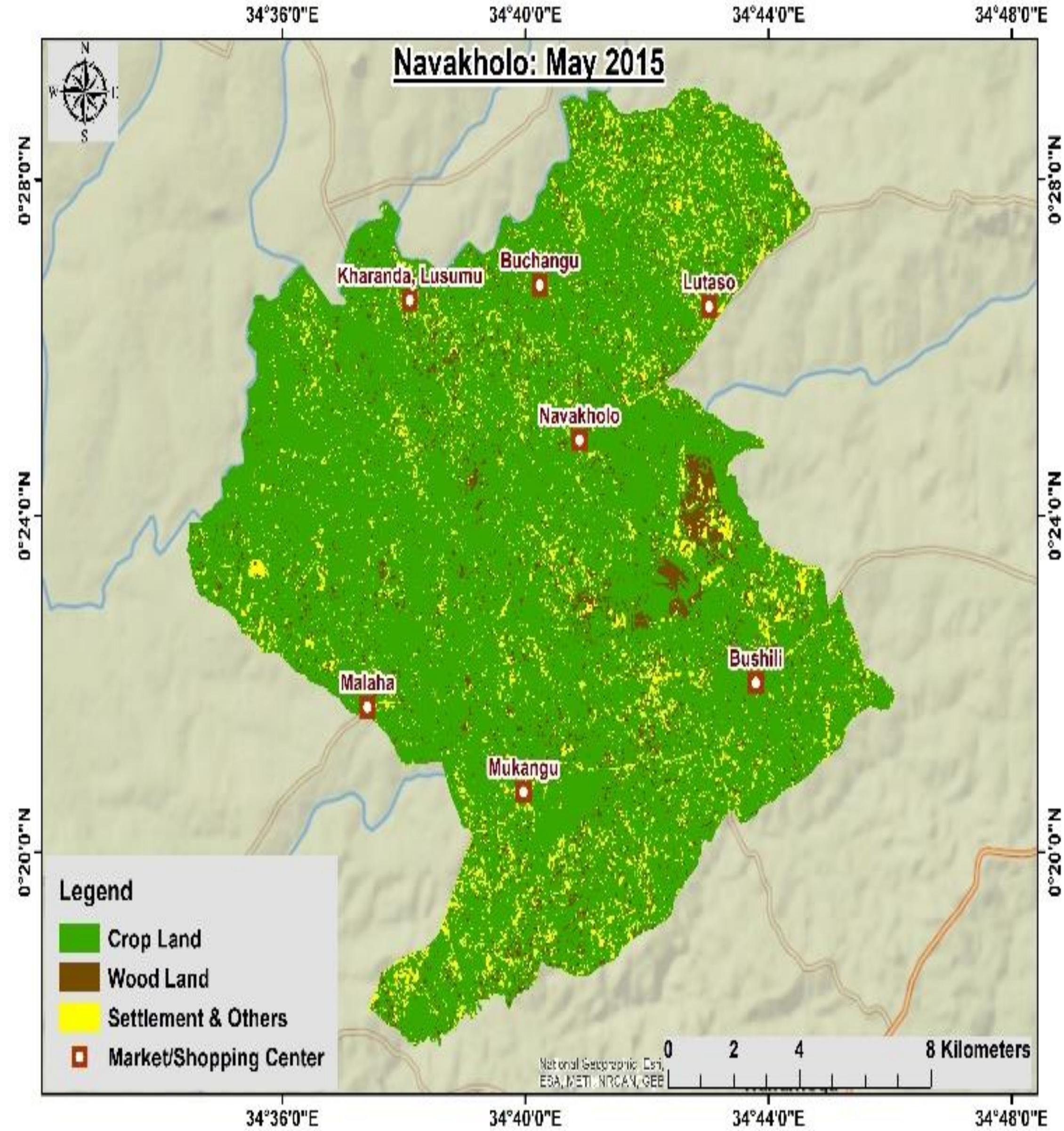

Figure 4.6: Land Cover Navakholo May 2015

(Source: Researcher: KU-GIS LAB 2023, Data source: ESRI Africa Geoportal)

Table 4.3: Trends in land use changes from (2005-2015) in hectares (Nearest whole number)

	2005	2010	2015	Net Change
Cropland	19,249	19,227	18,844	-405
Woodland	4,864	4,750	4,940	76
Settlement and other land uses	1,787	1,923	2,116	329

By 2020, there had been a net decline in cropland by 11.69%, woodland by 12.02% and a significant increase in settlement by 425.87% (Figures 4.7 and Table 4.4). A decrease in woodland area especially within households suggests future severe shortages in firewood and therefore the need to invest in measures that guarantee sustained supply of the same and also other energy alternatives. The increase in woodland between 2015 and 2020 was confined to protected land (Bunyala Forest), which indicates that current efforts in forest conservation are bearing fruit. Reduced cropland has implications on local food sovereignty.

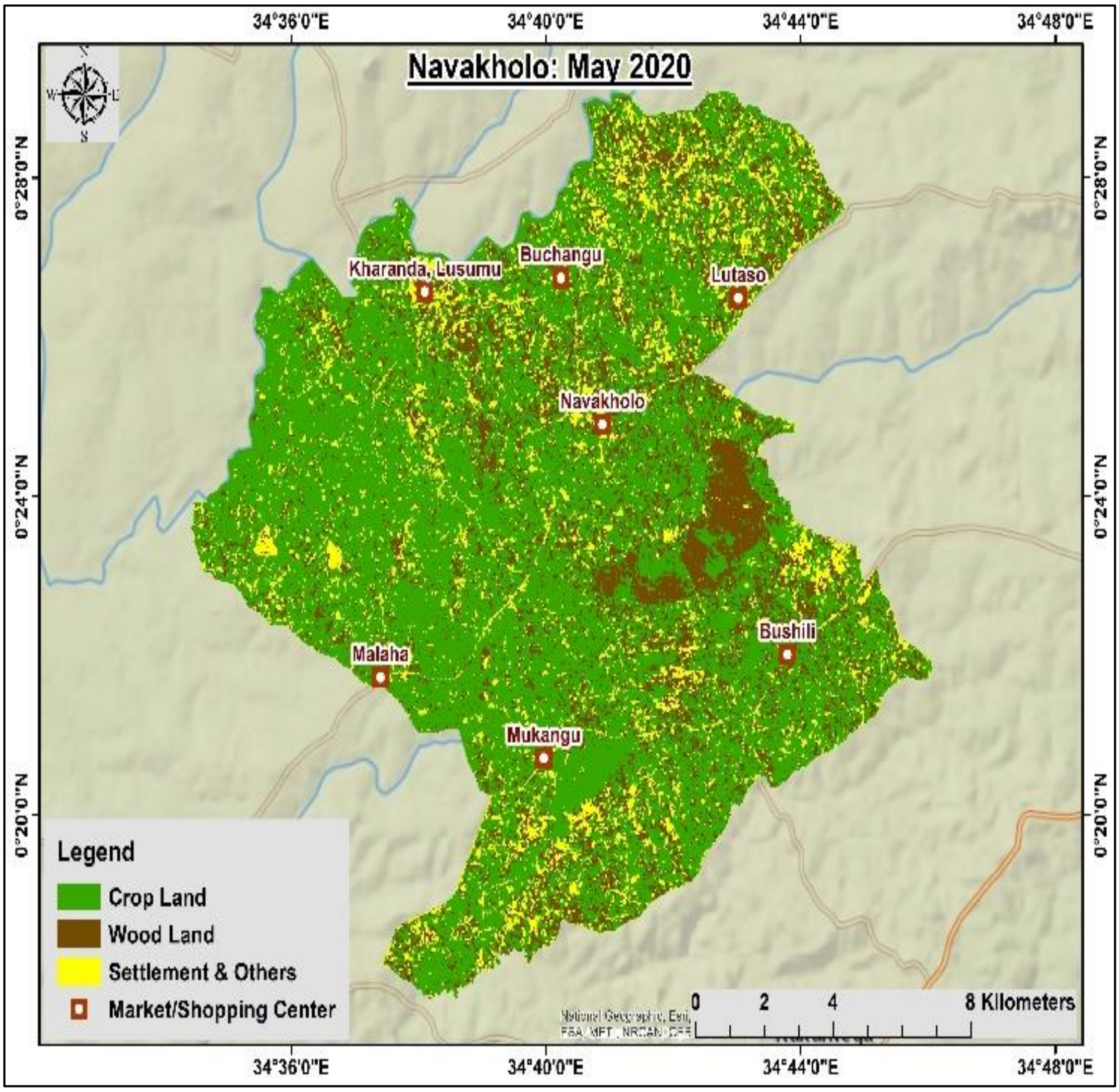

Figure 4.7: Land Cover in Navakholo May 2020

Table 4.4: Trends in land use changes from (1990-2020) in hectares

	1990	1995	2000	2005	2010	2015	2020	% Net change
Cropland	19,514	19,518	19,450	19,249	19,227	18,844	17,232	-11.69
Woodland	5,690	5,196	5,013	4,864	4,750	4,940	5,006	-12.02
Settlement and other land uses	696	1,187	1,437	1,787	1,923	2,116	3,662	425.87

The ensuing intensification of land use also increases the risk of land degradation, particularly under the current dispensation of devolved extension services that are not visible (Waswa, 2018)

Overall, increasing population pressure and declining household land sizes will need to be accompanied with strategic measures of increasing tree cover at that spatial level. Conservation of forested areas, re-afforestation and afforestation practices will contribute to increasing the share of tree cover within the sub-county (Brancalion & Holl, 2020). The Government through the Kenya Forest Service is committed to achieving 10% tree cover in the country (Mumina & Bourne , 2020).

Opportunities for increased tree cover lies in agroforestry system and practices that blend with cropland. Attention is being paid to integrated farming systems involving different components of agroforestry such as forest and fruit trees, plantation crops, cereal and pulse crops, medicinal and aromatic crops depending on the situation and requirement of the farmer (Chai, et al., 2021).More incentive for increased tree cover on agricultural land should be seen from the role of trees in mitigation of climate change (Chapman , *et al*., 2020).

Environmental checklist showed that majority of the households had trees either in the form of woodlots or planted along the fence. Firewood was used for cooking. Most of the respondents (78.9%) indicated that they had adequate tree cover. This was observed by presence of trees and woodlots in the homesteads.

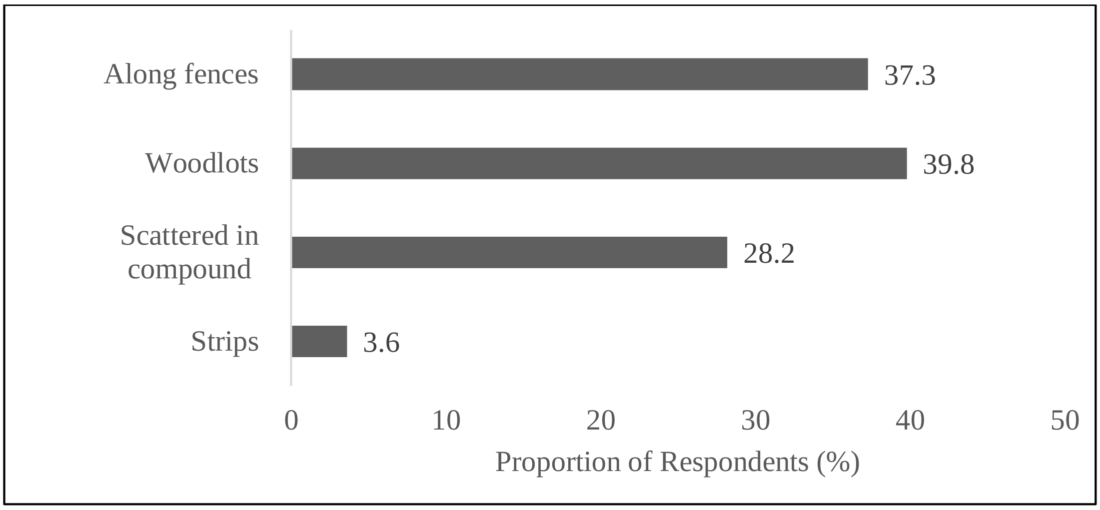

Figure 4.8: Tree cover practices among households

Woodlots occupied 39.8% of the tree cover patterns within the homesteads followed by trees planted along fences at 37.3% (Figure 4.8). Trees planted along the fence were used to mark boundaries, while trees planted in woodlots particularly eucalyptus were mainly for commercial purposes. Although eucalyptus is prohibited within riparian areas in Kenya, its ability to profusely sprout makes it a good source of wood fuel for domestic energy security. Land use planning at the household needs to integrate this tree among other species for this purpose and manage it in ways that enhance wider livelihood and environmental benefits. A study in Ethiopia on carbon content in agroforestry practices showed that woodlots had significantly higher above ground tree carbon, total tree biomass carbon, and total carbon followed by home gardens and parklands (Bajigo et al., 2015).Woodlots have advantages including the fact that they required little land and labour e.g. weeding is only necessary during early growth, furthermore many trees receive no cash inputs or only minimal amounts for the purchase of seeds or seedlings as compared to other agroforestry practices (Gandapa, *et al*. 2022). With the availability of woodlots, respondents did not have to go far to access firewood. Access to fuelwood from neighbouring farms was hampered by the fact that one had to seek permission to access fuelwood therefore it depended on the relationship one had with their neighbours. Tree growing on farms has been acknowledged as a fundamental source of wood in the country (Ministry of Environment, Water and Natural Resources , 2013). Dynamic management of woodlots with early maturing tree varieties with ability to sprout upon harvesting provides the way forward for household energy security.

Table 4.5: ARIMA Model Parameters

		Estimate	SE	t	Sig.
Tree/ forest cover (%)-Model_1	Tree/ forest cover (%)	19.557	.450	43.494	.000
Crop land - Model_2	Crop land	19004.899	308.515	61.601	.000
Wood land-Model_3	Wood land	5065.406	116.398	43.518	.000
Settlement and other land uses-Model_4	Settlement and other land uses	1829.691	355.312	5.150	.002

The model predicts a future five years from 2020 (2025) increase in the percentage tree cover by 19.56%, crop land will increase to 19004.9 Ha, woodland will increase to 5065.4 Ha and area under settlement will reduce to 1829.69 Ha (Table 4.5, Fig 4.9).

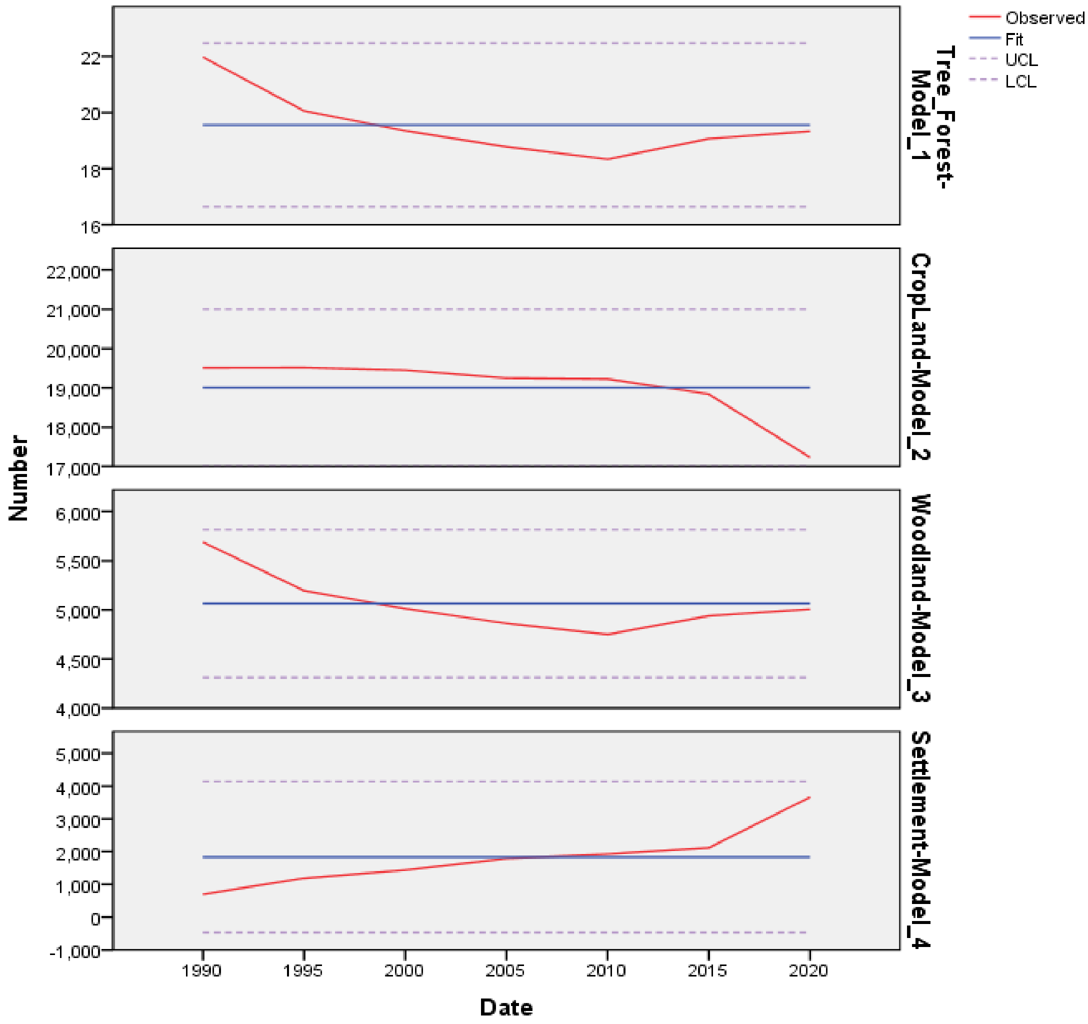

Figure 4.9: Land-use trends from 1990 to 2020

The p values are significant showing that for tree/forest cover, cropland, woodland and settlement and other uses p<0.05, therefore the null hypothesis that there has been no significant change in tree and forest cover from 1990-2020 is rejected. The future in this scenario consists of an increase in tree and forest cover and crop land, a decrease in settlement leading to an adequate supply of biomass, and sustainable use of resources thus reducing the supply and demand enhancing sustainable use and management of resources. The model predicts a dip in settlements and other land uses. This may be attributed to a proper planning of settlements, slowing down the development of settlement within the sub-County and a shift in supporting agriculture and woodlands to sustain the needs of its population. On the other hand, proper planning and management approaches to available land for settlement might prevent the expansion of settlements thereby creating space for cropland and woodland.

4.4. Tree Cover, Availability and Access of Biomass Energy at Household Levels

4.4.1 Status of Biomass Energy Options and Their Relative Importance

Firewood was the most popular energy source that was used very often at 90.4% as expected for rural farming households, followed by crop residue (often used by 41.6%) followed by charcoal that was used often at 31.7% (Figure 4.10). This is in line with studies on determinants of household energy choices in Ethiopia that showed that 90.7% of households used firewood as their primary source of energy for cooking (Wassie, Rannestad , & Adaramola, 2021). In Tanzania 88% and 30% of the rural population use firewood and charcaol resposectively (Olabisi *et al*., 2019). Baning of the sale and transportation of charcoal as is currently the case in Kitui County and a nationwide logging moratorium could be counterprodcutive as bans do not infact reduce production but drive producers underground (Gonzalez, 2020). Thus there is need for sustainable charcoal production through the use of energy efficient kilns.

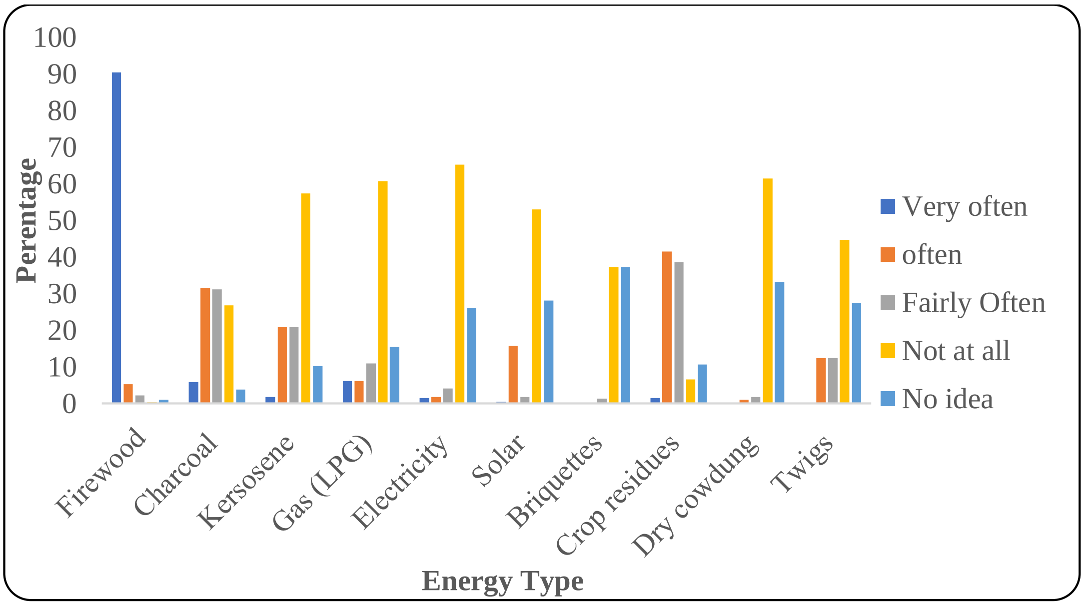

Figure 4.10: Use of energy types in households

Firewood was most popular because its easily available and has been used over the years. To balance between expected increased demand for firewood and maintenance of envisaged tree and forest cover, innovative tree stewardship at the households is inevitable. Tree stewardship at the household levels involves planting and nurturing the trees such that they are able to grow to their full potential, collecting dry branches and pruning as opposed to cutting down the whole tree to reap maximum benefits from the trees, growing trees that serve different purposes such that trees are able to effectively compete with other conflicting uses within the farm. Value addition in terms of using by-product of wood such as saw dust, creation of briquettes and use of energy efficient stoves.

According to the study, crop residues included the use of maize cobs and straw. Among the households, 41.6% used crop residues often while 38.6% used crop residues fairly often. This shows that crop residues are also quite popular within the households. They are used when there is scarcity of fuelwood, thereby reducing pressure on tree cover. Maize cobs are used as a component of briquette production thereby adding value, though this does not happen in Navakholo. This concurs with a study on crop use as a potential energy source that stated that crop residues could meet 91% of Ghana's energy demand (Azasi, *et al*., 2020).

According to the study, 59.4% stated that they had not used briquettes. These statistics point to a glaring gap in regards to knowledge and perception of briquettes as a source of energy within the household. Briquettes have not been widely adopted in developing countries due to the high cost of production, lack of awareness on its sustainability, lack of ready market and poor packaging and distribution systems for the product (Emerhi, 2011). Respondents were asked if they used dry cow dung as an energy source. Up to 61.4% did not use cow dung at all, 33.2% had no idea of the use of cow dung for energy. A study in India showed that households relied on a combination of dung cakes (flat disks of dried cow dung approximately ten centimetres in diameter) for cooking, and the remaining 27% was discarded to the environment leading to environmental pollution (Shaibur , Husain , & Arpon, 2021). The dung cakes were made in the cooler months whereby wet dung from buffalo is gathered, shaped by hand into cakes and left to dry for three to seven days and the stored in communal spaces. During cooking, dung cakes are broken up by hand and fed into the fire. According to Shaibur *et al*., (2021), dung cakes create a significant amount of smoke when its first lit, but once its burning, the smoke subsides. The dung does not burn as hot as wood and is used for purposes such as boiling milk. Further majority of the households 44.7% did not use twigs at all while 27.4% had no idea about the use of twigs as a source of energy in the household. This is explained by the fact that twigs are used as a combination with other fuel sources, and it was not as effective as fuelwood. Therefore, the use of twigs does not reduce pressure on tree cover. However, up to 12.4% of the respondents agreed to using twigs often as a source of fuel. The results show that the use of twigs is not very popular in households.

Firewood, charcoal, and crop residues are relied upon to cater for energy sources within the household. This is due to their availability. Briquettes were not popularly used due to lack of technical know-how on how to produce them. Cow dung was not used as it is viewed as archaic. This shows that households in Navakholo heavily rely on biomass to cater to their energy needs.

The mean rating of respondents' access to biomass-based energy ranged from 1.63 to 4.86 in a five-point Likert scale (Table 4.6). This implies that an average individual from the sampled population is likely to be accessing firewood very often (4.86 = 5 in the Likert scale). Access to charcoal (3.09 = 3 in the Likert scale) and crop residue (3.17= 3 in the Likert scale) by an average individual from the sampled population is rated as fairly often. However, twigs (2.15 = 2 in the Likert scale), briquettes (1.63= 2) in the Likert scale, cow dung (1.7 = 2 in the Likert scale) are not used by an average resident of Navakholo Sub-County. Twigs are not used as a fuel option in the household because of the long time it takes to gather the twigs and also in the event that you light the fire, longevity is not guaranteed. Respondents did not use briquettes as they were not aware of their use and the fact that they were not easily available.

Table 4.6: Mean rating of household access to biomass-based energy options

	N	Mean	Std. Dev	Std. Error Mean
Briquettes	386	1.63	0.509	0.026
Cow dung	384	1.70	0.976	0.028
Twigs	388	2.15	1.015	0.052
Charcoal	392	3.09	0.985	0.050
Crop residue (cobs, straw)	390	3.17	0.976	0.049
Firewood	391	4.86	0.550	0.28

The mean access to firewood, charcoal, crop residue, and twigs were significantly different from 2 (Not used at all) as hypothesized. Further, the respondents' access to the biomass energy sources had p values of p=.000. (Table 4.7). This means that an average resident rated their access to the different sources of biomass above 2 (Not used), except for briquettes and cow dung. As shown above 2 in the Likert scale implies zero access to the energy resource. Therefore, residents were accessing firewood, charcoal, crop residues and twigs. Therefore, the null hypothesis that farm households in Kakamega County do not access quality biomass-based energy is rejected.

Table 4.7: Testing mean access to Biomass energy sources

	Test Value = 2					
	t	**Df**	**Sig. (2-tailed)**	**Mean Difference**	**95% CI of the Difference**	
					Lower	**Upper**
Firewood	102.706	390	0.000	2.857	2.80	2.91
Charcoal	21.853	391	0.000	1.087	0.99	1.18
Crop residue	23.649	389	0.000	1.169	1.07	1.27
Twigs	2.851	387	0.005	0.147	0.05	0.25
Briquettes	-14.199	385	0.000	-0.368	-0.42	-0.32
Cow dung	-10.622	383	0.000	-0.302	-0.36	-0.25

4.4.2. Correlation between Tree and forest cover and preference of energy source

Among the respondents, 79% agreed to having appropriate tree cover, 21% did not agree that they had appropriate tree cover. Table 4.7 shows correlations between the energy sources used in relation to household tree cover. Relationship between forest cover and preference of energy source was established using Pearson correlation tested at P≤ 0.05. In Homestead where residents often preferred firewood, there were significantly no appropriate (ten percent threshold) tree cover (r = 0.104, P = 0.040). In homestead where residents often preferred charcoal, Gas, electricity, Briquettes, cow dung or twigs, there were significantly appropriate tree cover (P < 0.5). This was showed by the negative correlation values, table 4.8. Charcoal is normally purchased or acquired from sources outside the home, which also indicates the need for households having some kind of income security. To sustain this income flow, trees planted within the home were used for other commercial purposes not necessarily to cater for energy needs within the household.

Table 4.8: Correlation analysis of appropriate tree cover and preference of energy source

		Does your homestead have appropriate tree cover
Firewood	r-value	0.104*
	Sig. (2-tailed)	0.040
Charcoal	r-value	-0.282**
	Sig. (2-tailed)	0.000
Kerosene	r-value	-0.073
	Sig. (2-tailed)	0.154
Gas	r-value	-0.152**
	Sig. (2-tailed)	.003
Electricity	r-value	-.154**
	Sig. (2-tailed)	0.002
Solar	r-value	-0.099
	Sig. (2-tailed)	0.051
Briquettes	r-value	-0.201**
	Sig. (2-tailed)	0.000
Crop residue e.g. cobs	r-value	-0.024
	Sig. (2-tailed)	0.632
Cow dung	r-value	-0.196**
	Sig. (2-tailed)	0.000
Twigs	r-value	-0.161**
	Sig. (2-tailed)	0.001
	N	389

4.4.3 Regression Analysis

Correlation analysis showed the strength of the relationship of the tested factors (charcoal and cow dung) the excluded factors were firewood, briquettes, crop residues, briquettes and twigs. The other factors were excluded as they did not have the strongest effect on the model. Stepwise regression analysis was used to select the independent variable to be used in the final model. It is used to see how the variance changes by adding or removing each predictor to the model one at a time. In this case the energy sources were added to the model and the one that had the strongest effect was chosen. The model was used to address objective number two that determines the relationship between tree and forest cover with availability and accessibility of biomass energy options at the household level. It was established that, using stepwise regression analysis, strongest effect on appropriate tree coverage was preference for charcoal and cow dung. Other factors were excluded in the regression equation. The model equation was therefore; $Y = \text{constant} + \beta_1 X_1 + \beta_2 X_2 + \varepsilon$

Where; Y = Tree cover, β = beta coefficient, X_1 = charcoal energy, X_2 = Cow dung, ε = error term.

Using unstandardized beta coefficient, this predictive model equation therefore becomes;

$Y = 1.527 – 0.097X_1 – 0.045X_2$.

The model therefore explains that in homestead where residents preferred using charcoal and cow dung for their energy sources, tree cover was not appropriate (Table 4.9). The measurement for appropriate is tree cover is the proportion of trees occupying ten percent of land within the homestead.

Table 4.9: Regression result tree cover and of preference of energy source

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.466	0.048		30.784	0.000
	Charcoal	-0.111	0.019	-0.295	-5.878	0.000
2	(Constant)	1.527	0.051		29.776	0.000
	Charcoal	-0.097	0.019	-0.259	-5.082	0.000
	Cow dung	-0.045	0.015	-0.153	-3.008	0.003

a. Dependent Variable: Does your homestead have appreciable tree cover

4.5. Status of Biomass Value-addition

. Overall, results showed that value-addition on biomass is generally non-existent in the sub-county. Firewood is still the most popular biomass option for cooking and heating in Navakholo. Charcoal comes in second as a standby option for special cooking and when the cold weather makes use of firewood a challenge. Use of biogas is rare because most households do not have zero-grazing units, which makes accumulation of cow dung difficult. In addition, the cost implication is a key disincentive even to the few farmers who have semi-intensive grazing systems. Yet with only 2 dairy cows under zero-grazing system, a household can harness biogas for all its cooking needs (Wachera, 2017). Use of saw dust balls as a binder material was not observed. All respondents indicated not having seen any household using design briquettes obtained from agricultural by-products (Tables 4.10).

Table 4.10: Popularity of Biomass energy options among households in Navakholo

Administrative Ward	Firewood	Charcoal	Biogas	Dung-Soil Balls	Saw Dust Balls	Design Briquettes
Bunyala Central	4	3	2	1	2	1
Bunyala West	4	3	2	1	2	1
Bunyala East	4	2	1	1	2	1
Ingotse-Matiha	4	2	1	1	1	1
Shinoyi-Shikomari-Esumeiya	4	3	1	1	2	1

Likert Scale Key: 4=Very high; 3=High; 2=low; 1= not observed

With regards to sources of biomass energy, firewood was mainly obtained from own farm wood lots and purchased from vendors. Charcoal was mainly purchased by those able to (Table 4.11).

Table 4.11. Sources of Biomass Energy Options within households

	Firewood		Charcoal		Saw dust		Cow dung		Maize cobs and stubble)	
	F	% F	F	% F	F	% F	F	% F	F	% F
1. Forest reserve	7	23.3	3	10.0	2	6.7	--	--	--	--
2. Own farm	15	50.0	7	23.3	4	13.3	--	--	7	23.3
3. Distributors	14	46.7	11	36.7	5	16.7	--	--	--	--
4. Off-farm sources	--	-	6	20.0	3	10.0	1	3.3	--	--
5. Local purchase	24	80.0	11	36.7	6	20.0	--	--	--	--

Saw dust is often seen as a free good to be taken from timber production sites. However, as an alternative source of energy in cook stoves, some vending on it is starting to emerge. Cow dung remains largely non-existent as a possible source of energy or even as a binder in making energy balls from other materials like charcoal dust. Maize cobs and stubble are seasonally available after every harvest. Farmers often use them when dry to supplement firewood. The lost opportunity is however how to turn them into design briquettes for enhanced energy supply and efficient use. Investment in briquetting needs to begin from formalized bulking and delivery of cobs to designated processing centres within the county. Such small-scale processing can be funded through county budgetary allocations or incentives given to private investors and civil society organisations.

In terms of continual supply of energy emphasis was put on firewood, saw dust and charcoal, including conventional management practices such as routine re-planting, dry storage and extinguishing remaining amounts after each days cooking (Table 4.12). Extinguishing charcoal and firewood, and saw dust after the days cooking is an indication of the severe scarcity of wood fuel. Through FGDs, it was noted that dry saw dust compacted in a clay cook stove can cook for 8 hours - generally enough for a day’s three meals. Despite its demonstrated potential elsewhere in Kenya as demonstrated by Chweya (2020), there was no mention of briquetting as a value-addition option. Saw dust is often abandoned to its own fate in situ and sometimes burnt.

Table 4.12: Responses on the Management of Biomass Energy Options

	Firewood		**Saw dust**		**Charcoal**	
	F	**% F**	**F**	**% F**	**F**	**% F**
1. Extinguishing after cooking	5	16.7	3	10.0	8	26.7
2. Selling specific weights or sizes	18	60.0	2	6.7	8	26.7
3. Regular re-planting	21	70.0	--	--	6	20.0
4. Chopping to fit cooking facility	17	56.7	--	--	1	3.3
5. Dry storage	19	63.3	6	20.0	5	16.7

Cow dung was used by few for composting and making organic manure. No respondent indicated using cow dung feedstock in biogas production. Maize cobs were mainly used on the farm to supplement firewood for cooking. Some of it was simply disposed-off by burning (Table 4.13). These management practices particularly burning of feedstock or just abandoning it in situ reveal a huge gap in knowledge on value-addition options. The potential of charcoal dust as raw material in briquetting was also untapped. Overall, correlation analysis between biomass types and management practices, which respondents thought (though erroneously) as aspects of value-addition practices showed significant relations especially for charcoal in terms of adding value through extinguishing after cooking (R=0.543), dry storage (R= 0.466), and selling specific weight sizes (R = 0.505). For firewood significant correlations existed in dry storage (R= 0.471) and chopping to fit the cooking facility in use (R= 0.554) (Table 4.14). These management practices are rudimentary. Much more benefits lie in replacing them with investments in briquetting technology.

Table 4.13: Opinions on the Disposal of Surplus Biomass

	Firewood		**Charcoal**		**Saw dust**		**Cow dung**		**Maize cobs and stubble**	
	F	**% F**	**F**	**% F**	**F**	**% F**	**F**	**% F**	**F**	**% F**
Own farm use	19	63.3	12	40.0	8	26.7	--	--	8	26.7
Sell to neighbours	19	63.3	12	40.0	9	30.0	--	--	1	3.3
Sell at local markets	24	80.0	12	40.0	9	30.0	--	--	--	-
Abandon on site	--	--	--	--	3	10.0	1	3.3	--	--
Collect and dispose	--	--	--	--	1	3.3	--	--	2	6.7
Composting and manuring	--	-	--	--	--	--	20	66.7	3	10
Burn on site	--	--	--	--	2	6.7	-	-	2	6.7

Table 4.14. Correlating Biomass value-addition Practices and Biomass Type

		Firewood	Charcoal	Saw dust	Cow dung
Extinguishing after cooking	Pearson Correlation	0.338	0.543**	0.579**	0.541**
	Sig. (2-tailed)	0.068	0.002	0.001	0.002
Dry storage	Pearson Correlation	0.471**	0.466**	0.746**	0.000
	Sig. (2-tailed)	0.009	0.009	0.000	1.000
Selling specific weights or sizes	Pearson Correlation	0.333	0.505**	0.563**	-0.213
	Sig. (2-tailed)	0.072	0.004	0.001	0.258
Chopping to fit cooking facility	Pearson Correlation	0.554**	0.235	0.391*	0.152
	Sig. (2-tailed)	0.001	0.211	0.033	0.424

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed). (N=30)

4.6. Other Challenges and Opportunities for Enhanced Household Energy Solutions

4.6.1 Weather and its Effects

Trends of wood fuel availability in households throughout the year showed that wood fuel was easily available and accessible in December to February, which is the dry season and very scarce from March to July, which is the rainy season (Figure 4.11 and Table 4.15). Private land tenure rightly restricts people open access to wood fuel from their neighbour’s farms. Even when wood fuel may be available in certain months, access is constrained by cost implications. Increasing tree cover restricted access to wood fuel where trees particularly eucalyptus were grown for commercial purposes. Access to wood fuel in protected areas (forest reserves) was also restricted by prevailing forest conservation regulations.

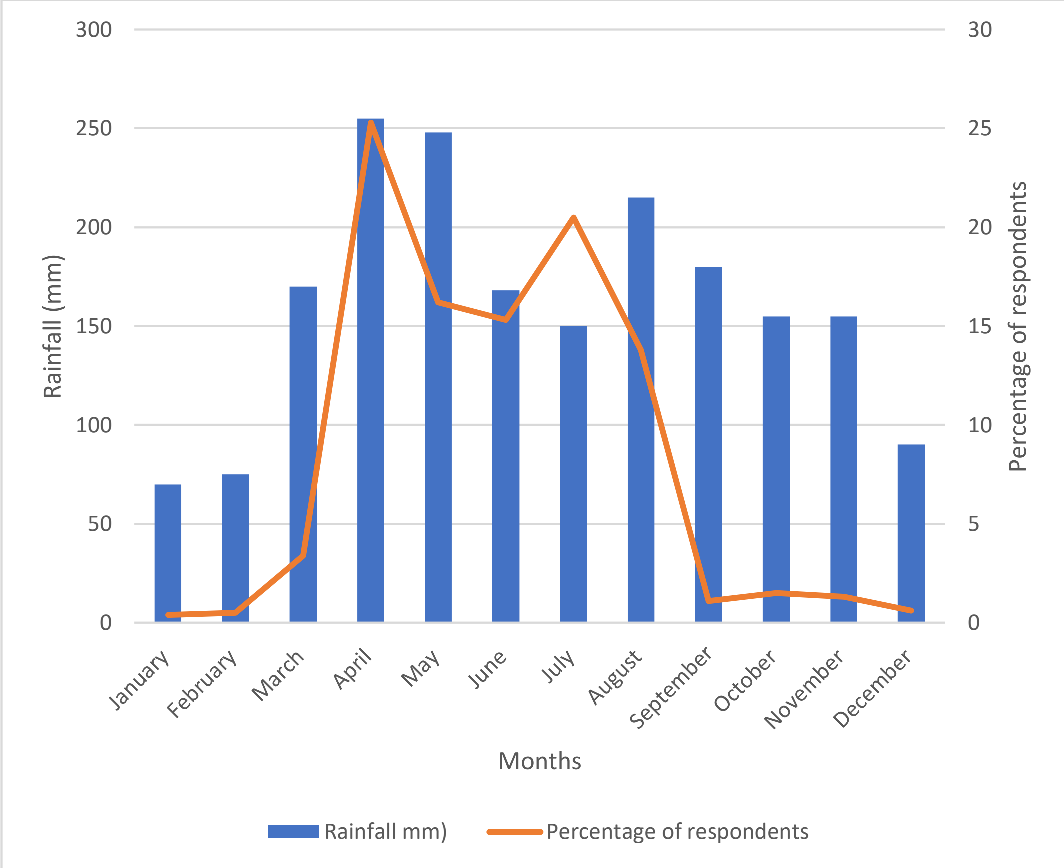

Figure 4.11: Trends in annual rainfall distribution and firewood shortage (Source: CGK, 2017)

Table 4.15: Month determinants of firewood shortages

		Wet weather	Land tenure restrictions	Cost of firewood bundles	Increasing Tree cover	Lack of energy alternatives	Scarcity at markets, hence high prices
Jan	F	1	1	0	2	1	0
	F %	0.3	0.3	0	0.5	0.3	0
Feb	F	3	0	1	1	1	0
	F %	0.8	0	0.3	0.3	0.3	0
Mar	F	35	6	3	3	1	1
	F %	9	1.5	0.8	0.8	0.3	0.3
Apr	F	287	28	32	19	5	4
	F %	72.8	7.1	8.1	4.8	1.3	1
May	F	180	28	15	15	2	2
	F %	45.7	7.1	3.8	3.8	0.5	0.5
June	F	175	24	8	11	3	2
	F %	44.4	6.1	2	2.8	0.8	0.5
July	F	255	25	33	18	7	2
	F %	64.7	6.3	8.4	4.6	1.8	0.5
Aug	F	153	20	10	15	5	2
	F %	38.8	5.1	2.5	3.8	1.3	0.5
Sept	F	7	1	3	5	4	0
	F %	1.8	0.3	0.8	1.3	1	0
Oct	F	16	0	5	6	1	0
	F %	4.1	0	1.3	1.5	0.3	0
Nov	F	12	1	4	3	2	0
	F %	3	0.3	1	0.8	0.5	0
Dec	F	5	1	0	3	0	1
	F %	1.3	0.3	0	0.8	0	0.3

As a natural survival response mechanism, which is also a cultural expectation, girls and their mothers with little financial power to buy wood fuel, have to walk for long distances in search of fuelwood, and in so doing exposing themselves to many risks, which trap them in a vicious cycle of human ill-being (Figure 4.12). Enhancing availability in this case calls for stocking dry wood fuel when the weather is favourable. Accessibility is also possible by buying from merchants, which however is constrained by income insecurity. Sustainable biomass energy solution at households thus calls for increasing tree cover and investing in alternative biomass energy options at individual households. The role of appropriate stocking and storage during the dry season remains a key adaptation measure that would minimize disruptions in cooking schedules in households.

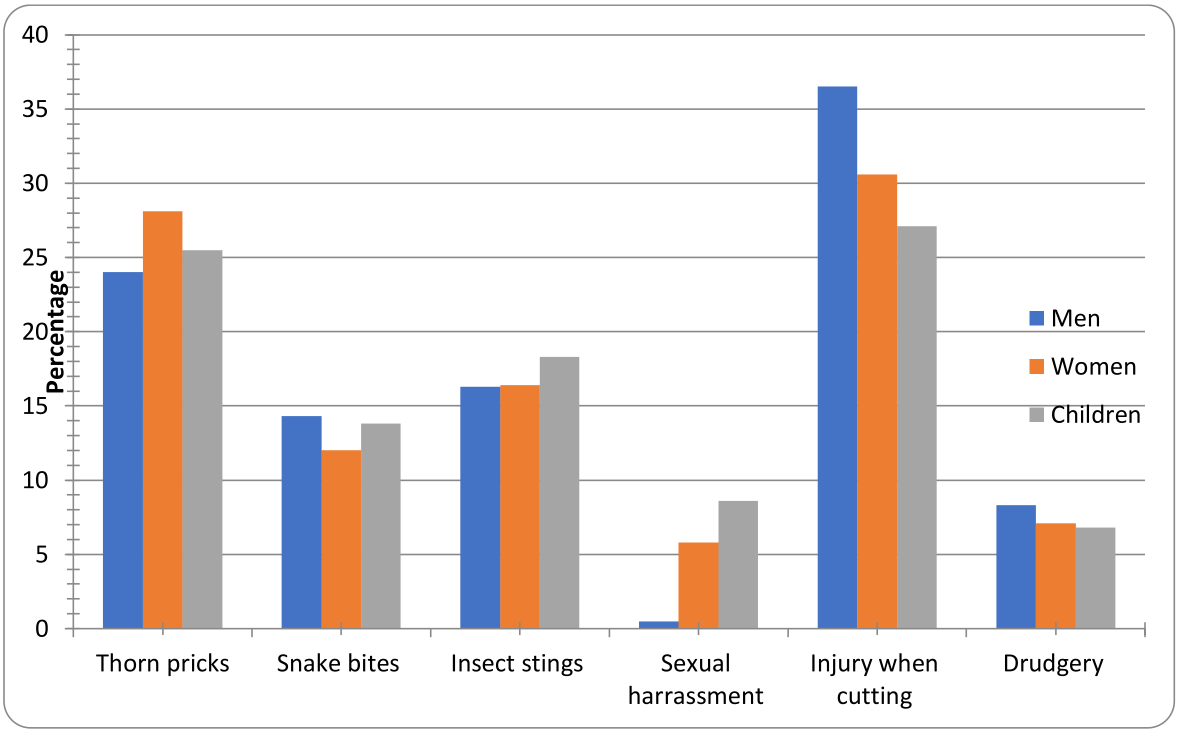

Figure 4.12: Dangers encountered while fetching fuelwood.

4.6.2 Ward-Specific Effects of Firewood Shortages

Effects of firewood shortages according to FGDs in Navakholo. In Bunyala Central effects of firewood shortage included conflicts, use of plastics for cooking which cause pollution (smoke and odour) and increased costs associated with firewood shortage. In Shinoyi-Shikomari-Esumeiya effects of fuelwood shortage included that cooking was a challenge, family disputes due to quarrels over the unavailability of fuelwood, stealing wood from neighbours, fences and use of furniture for cooking. In Bunyala East effects of fuelwood shortage include cooking problem, family disputes when the fathers begin to eat in nearby hotels, while the rest of the family starves at home, and stealing wood fuel from neighbours' fences. In Ingotse-Matiha effects of fuelwood shortage include theft (stealing of fences made of wooden poles) had increased leading to conflicts among neighbours. Life of girl child has become more vulnerable (In the evening after school they are forced to search for firewood thus having limited time to study, exposed to risks such as snake bites as they go to look for firewood, rape case). Other effects include women being bound to labour more in search of fire wood (walking long distances), family conflicts, cooking problems, use of plastics, mattress, furniture and polythene for cooking leading to pollution resulting in health problems. In Bunyala West the effects of fuelwood shortage include difficulties in food preparation, family conflicts, cutting down trees planted for other purposes like timber production, use of furniture for cooking and use of plastics (buckets and water cans) for cooking. Similar findings have been observed by among others Njenga *et al*., (2021), Kyayesimira and Muheirwe (2020). Rajput and Jadhay (2023) in particular pointed to the dangers of gender-based violence for women and girls who must spend long hours looking for firewood. The time spent and drudgery incurred prevents women from effectively engaging in their other core chores like caring for children, engaging in other income generation activities and even leisure for good health.

Focus group discussions revealed a myriad of measures taken by households to addressing the challenge of fuelwood shortages (Figure 4.13). At 30.6%) score, efficient use of firewood involved strategies like extinguishing firewood immediately, using firewood that burns slowly and cooking combined meals and skipping meals. Similar findings were observed by Waswa *et al*, (2020) in a study done in Meru County, Kenya. Shift to other energy sources (24.9%) included the use of other energy types such as charcoal, gas, briquettes and cow dung balls, whose adoption is however limited by among others the cost implications.

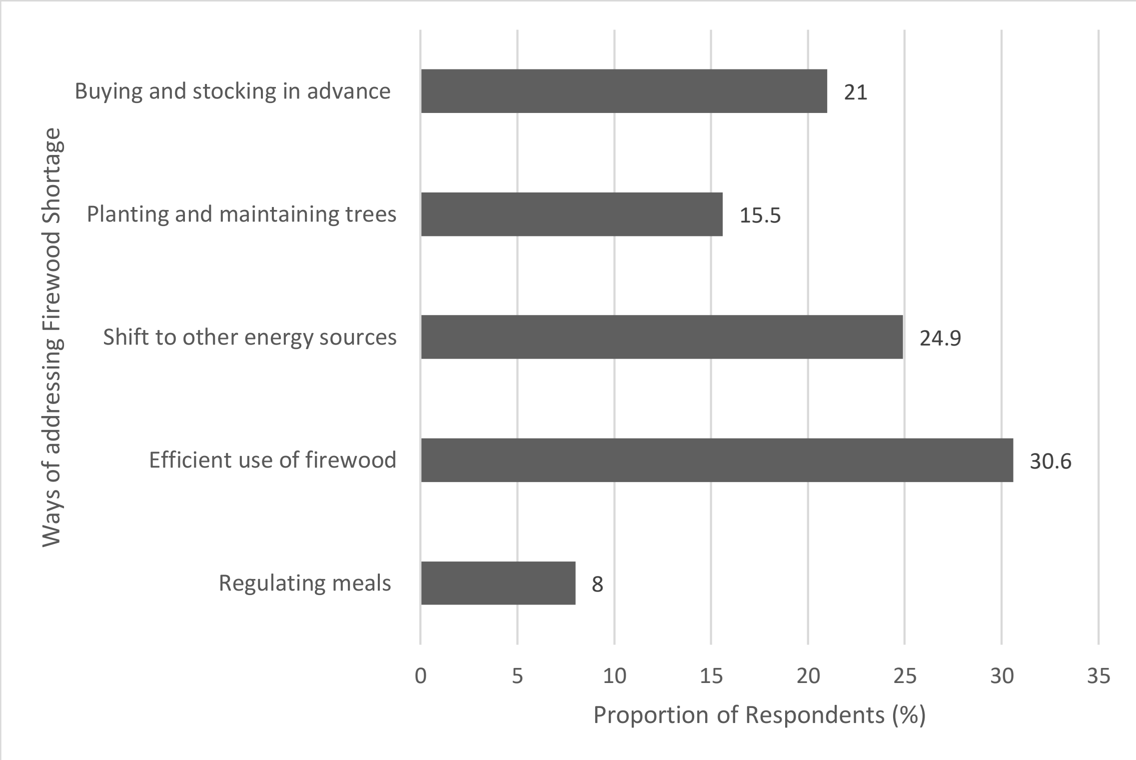

Figure 4.13: Measures to address fuelwood shortage

Key formant interview with the local forester identified the following strategies as being essential for sustainable use of biomass energy in resource-stressed rural communities.

1. Moving from traditional to use of improved cook stoves (ICS)
2. Investment in biogas
3. Use of sawdust in design cook stoves
4. Use of briquettes from locally available raw materials
5. Planting fast growing and multi-purpose trees.

While availability and access to briquettes may be restricted by cost implications, and while growing early maturing tree varieties is long term, studies elsewhere have shown that with only 2 dairy cows, a household can have enough raw material to run a small-scale biogas system for domestic energy supply (Wachera and Waswa, 2017). Although most households in Navakholo sub-county do not have zero-grazing systems, they have more than 2 local breeds, which are sheltered in a common place at night. Essentially, they too have enough raw material to run a small-scale biogas system. Incentives to enhance adoption in this regard must address the high initial capital required followed by target extension services for community capacity and competence development.

4.6.3. Fall-Back Energy Solution

In the event of total lack of wood fuel, respondents isolated kerosene as their preferred fall-back energy solution (Table 4.16). Although cheap and easily available, the use of kerosene releases smoke leading to indoor air pollution and health challenges. Burning of kerosene also releases greenhouses gases which contribute to climate change. Use of LPGs and electric energy sources is mainly constrained by the cost factor. Accordingly, biomass will remain the choice energy solution for a long time until the myriad alternatives are made accessible. Kenya’s energy policy needs to in particular expand the rural electrification programme by making connectivity affordable. The same applies to investments in solar energy.

Essentially enhancement of biomass energy solutions in resource-poor farming communities requires an integrated approach that includes sustainable forest management practices, efficient utilization of available wood resources, the promotion of agroforestry and alternative energy and cleaner sources (Bodur, 2023). The latter’s success is depended on availability of disposable income by households, which requires deliberate facilitation by multiple stakeholders led by the county government, to introduce commercial farming practices and off-farm income generation practices.

Table 4.16: Energy fall-back source when there is total lack of firewood

Fall back energy source	Frequency	% Frequency
1. Kerosene	160	40.6
2. Gas	98	24.9
3. Solar	49	12.4
4. Electricity	14	3.6
5. Biogas	2	0.5
6. Non-committal	71	18.0

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

The overall objective of this study was to assess the availability, access and use efficiency of biomass energy sources within rural households in Navakholo Sub-County in order to contribute to sustainable energy solutions in the context of declining supply of wood fuel.

On the first objective of the study it was evident that although land cover is dominated by cropland, woodland and settlements over time, there has been a general decrease in tree and forest cover from 1990 to 2015, though an increase in tree in forest cover was observed from 2015-2020. This is attributed to the growing human population and consequent pressure for settlements and more land for cultivation. Additionally, this translates into increased pressure on available biomass energy sources, in particular the already declining tree/forest cover. These factors pose a direct risk of land degradation in the short term and exacerbated impacts of climate change in the long term.

On the second objective, the study observed that a 78.9% of the respondents stated that they had adequate tree cover in the form of woodlots and partly as trees planted along the fences of their homes. For households that preferred to use charcoal and cow dung, tree cover was found inadequate. There was a significant relationship between household biomass usage and tree density and adequacy of fuelwood in the area. Correlations indicated an increase in the use of firewood is associated with a similar decrease in tree cover within the homestead and locality. In homesteads where households preferred to use charcoal and cow dung, tree cover was not appropriate.

On the third objective the study established that there was evidence of households converting firewood or other biomass by products like sawdust into new energy products. Briquettes and pellets were unheard of. Biogas too was non-existent where households had readily available raw material. Correlations show significant relationships between charcoal and dry storage and selling of specific sizes. For firewood significant correlations existed with dry storage and chopping to fit cooking facility. Awareness and investment in value-addition in biomass sources like sawdust, maize cobs, cow dung and post-harvest wastes like husks from groundnuts requires attention in expanding energy options in such areas. Tree planting, coppicing and pruning increased the availability of biomass. Regular tree planting, maintenance and care of the tree and sustainably managed tree plantations will lead to enhanced availability of biomass. Tree management involves certain management techniques such as pruning, lopping, pollarding, coppicing and thinning which are applied to trees and shrubs in the agroforestry system. These practices are applied to increase biomass. Lopping is different from pruning in that the branches do not get chopped off at the base but can be more haphazard. Coppicing entails chopping a tree down to the ground and letting it reshoot in multiple stems. It is a highly productive way of harvesting wood products particularly firewood in a regular and sustainable way. Pruning to recover specific sections of the tree is often a fall-back practice for accessing fuelwood.

5.2. Conclusions

There has been an overall decline in tree and forest cover within households due to changing land use patterns in favour of agriculture and settlement, but a slight increase in protected areas like Bunyala Forest in the period 1990-2020. As expected this decrease in tree cover is exacerbating scarcity of fuelwood, thus undermining environmental performance and human well-being. Households with relatively secure wood fuel had woodlots and trees along fences; mostly exotic varieties such as eucalyptus that grew fast and matured early. However, having significant tree cover in one’s compound did not necessarily translate into adequacy of fuelwood for the household. Trees in such homes were used for other purposes especially of commercial nature

To conserve firewood and charcoal, households extinguish them after the day’s cooking to be used during the next cooking. In some cases, combined cooking and skipping meals is used to prolong availability of firewood. As a fall-back position following severe shortage of firewood, most of the households preferred to use kerosene stoves.

Except for charcoal, which is not perceived as a value-added product, biomass value-addition is non-existent in the area, despite its huge potential from a wide range of available agricultural biomass. Demand for biomass energy still exceeds supply, which is undermined by financial constraints and the weather. Opportunities for enhanced availability and efficient use of biomass lie in value addition of a wide range of agricultural by-products on the farms.

Overall, fuelwood remains the preferred energy source due to its affordability, as such the future of household energy security lies in afforestation practices that are suitable for declining land sizes, and more efforts in promoting use of other biomass energy options that reduce pressure on tree cover

5.3 Recommendations

On the basis of the above conclusions, the following key recommendations are made.

i. There is need for investment in more trees for more biomass energy within households through agroforestry practices like woodlots, trees on fences and proper planning to manage the competing land uses particularly settlements.

ii. There is need to invest in alternative energy options in order to reduce heavy reliance on trees. Since most households have livestock, affordable biogas digesters would be a strategic entry point.

iii. The potential for value-addition on biomass is huge and lies in harnessing readily available agricultural by-products for briquettes, especially using maize cobs with the appropriate binder.

iv. Use of improved cook stoves towards biomass energy efficiency and maintaining stocks of firewood within changing weather patterns are key management requirements that should be nurtured through targeted extension services by both the ministry of agriculture, the Kenya forest service, Private sector and civil society.

In terms of further research, the following areas are merit consideration:

i. How to shift from planting to growing and managing the appropriate tree species within diminishing land sizes for sustainable biomass energy supply
ii. A feasibility study on the quantities and quality of agricultural biomass with view of establishing mini-briquetting factories for rural energy security in the sub-county
iii. At the policy level, strategies of reducing investment costs of clean energy options would enhance their adoption and hence reduce pressure on biomass energy, thus contributing to energy security in rural agro-ecosystems.

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APPENDICES

Appendix 1: Household Questionnaire Survey

Date of Interview ___________________Questionnaire No.__________________________

Section A: Background/ socio-economic data (Tick as applicable**)**

1. County Ward

a. Ingotse-Matiha ( )

b. Shinoyi- Shikomari-Esumeiya ( )

c. Bunyala West ( )

d. Bunyala East

e. Bunyala Central ( )

2. Sex of the respondent

a. Male ( )

b. Female ( )

4. Age of respondent (**optional**)__________________

1. Size of household_______

2. Source of household income_____________

a. Formal employment ( )

b. Business ( )

c. Casual labour ( )

d. Farming ( )

e. Boda Boda ( )

3. Income range per month (**optional**)

3.5.Less than Kshs 5000 ( )

3.6.Kshs 5001 – 10000 ( )

3.7.Kshs 10001 – 15000 ( )

3.8.Kshs 15001 – 20000 ( )

3.9.Above Kshs 20000 ( )

Section B: Status of Biomass Energy Options (Tick as applicable)

1. Does homestead have significant tree cover (YES….) (NO…….) (tick)
2. If YES under which pattern:

   a. Woodlots ( ); b) A long fences ( ); c) Scattered in the compound ( ) d) Strips ( )

3. How does tree density today compare with that of 5 years ago?

a. Has remained the same ( )

b. Has increased ( )

c. Has declined ( ),

d. Its more exotic than indigenous ( )

4. How often do you use the following energy sources (where 5: Very often, 4: often, 3: fairly often; 2: not at all; 1: No idea

Energy type	**5**	**4**	**3**	**2**	**1**
1. Firewood					
2. Charcoal					
3. Kerosene					
4. Gas (LPG)					
5. Grid Electricity					
6. Solar					
7. Briquettes					
8. Maize cobs, straw, crop residues					
9. Dry cow dung					
10. Twigs					
. Any other (specify) …………………………………………					

10. What are the reasons for your preferred energy type? (Several ticks allowed)

a. Affordable ( )

b. Easy to use ( )

c. Easily available ( )

d. Not dangerous ( )

e. Burning characteristics ( )

f. Smokeless burning ( )

g. Influences flavour of food ( )

h. Ease of storage ( )

i. Portability ( )

j. Others (specify)________

11. How would you rate the adequacy of your fuel wood today supply (Tick appropriate box)?

1	Very inadequate	**2**	Inadequate	**3**	Adequate	**4**	Very adequate

12. From where do you get your biomass energy (firewood)?

a. Buy from market ( )

b. From neighbours' farms ( )

c. Household wood lot ( )

d. Other places e.g., government forest______________________(provide name)

7. What is the furthest distance you cover to fetch firewood?

a. Up to 2 km ( )

b. Up to 4 Km ( )

c. Up to 6 Km ( )

d. Up to 8 Km ( )

e. Up to 10km ( )

f. >10 Km ( )

15. How often do you collect/fetch firewood?

a. Daily ( )

b. Weekly ( )

c. Monthly ( )

d. Quarterly ( )

e. Annually ( )

16. What are some of the dangers/problems reported by those who fetch firewood for the family?

Dangers encountered	Men	Women	Children
Thorn pricks			
Snake bites			
Insect stings			
Sexual harassment			
Injury when cutting			
Drudgery			
Unwanted pregnancies			
Others			

11. In which months is firewood shortage most severe? (Tick appropriate)

J	F	M	A	My	Jn	Jy	A	S	O	N	D

19. What are the causes of this shortage?

a. Cost ( )

b. Lack of energy alternatives ( )

c. Declining tree cover ( )

d. Limited availability at the Markets ( )

e. Land tenure restrictions ( )

f. Bad weather (Rains)

g. Others (specify)_______________

14. How do you address or overcome this shortage?

a. Skipping meals to save energy ( )

b. Cooking combined meals ( )

c. Cooking only once or twice/day ( )

d. Buying and stocking in advance ( )

e. Shifting to other energy types like Gas, Kerosene, electricity ( )

f. Using charcoal

g. Planting and maintaining trees in the compound ( )

h. Shifting to briquettes, cow dung balls, charcoal dust balls ( )

i. Using firewood that burns slowly

j. Extinguishing firewood immediately food is cooked ( )

k. Use of energy-saving cook stoves ( )

l. Specify any other measure……………………………………….

SECTION C: Status and potential of Improved Cook Stoves

21. Which type of cooking stove do you **use** in your household? (Tick accordingly)

Traditional 3 stone stove	
Kuni mbili	
Normal metal jiko	
Improved cook stove	
Specify any other (	

22. If Household is not using Improved Cook Stoves (ICS) rank the reasons for not adopting the improved cook stove in the table below

Barriers to the use of ICS	**Very true**	**True**	**Not true**	**Don't know**
Are expensive				
Not aware of their existence				
Do not find them appropriate				
Not readily available at the market				
Any other (specify)				

SECTION D: Effects of management regimes on availability, access and use of energy options at the household

23. How would you rate the adequacy of household fuel wood5 years from now?

Very adequate	1	Adequate	2	Inadequate	3	Very Inadequate	4

24. Why do you think fuel wood(firewood) will be adequate?

a………………………………………………………………………………………

b………………………………………………………………………………………

c………………………………………………………………………………………

d………………………………………………………………………………………

25. Why do you think the firewood will be inadequate?

a………………………………………………………………………………………

b………………………………………………………………………………………

c………………………………………………………………………………………

d………………………………………………………………………………………

26. Does the tree species matter in your firewood management choices? (Yes) or (No)

27. If YES, which species characteristics do you prefer

a. Early maturing ( )

b. Sprouting type ( )

c. Fruit species ( )

d. Resistant to termite attack ( )

28. Which tree species are dominant in the homestead?

a) Indigenous (…)

b) Exotic ( )

SECTION E: Challenges and Opportunities in the uptake of biomass-based energy sources and adoption of alternative Energy Sources

29. Why do you find it difficult to invest in biomass energy solutions on a sustainable basis?

a. It is expensive ( )

b. Lack of own land ( )

c. Available land is needed for other more important uses ( )

d. Lack of knowledge on value-addition on biomass energy ( )

e. Other (specify)___________

30. What would be your next fall-back energy source in case of total lack of firewood? (Only one choice needed)

a. Electricity ( )

b. Solar ( )

c. Gas ( )

d. Kerosene ( )

e. Biogas ( )

f. Other (specify)________________

31. Provide your reasons for the choice in 30 above

a…………………………………………………………………………………………

b…………………………………………………………………………………………

c…………………………………………………………………………………………

32. How in your opinion can households be facilitated to invest more in cleaner energy alternatives?

a. Increase awareness on the benefits of alternative energy sources ( )

b. Provide technical training on their use ( )

c. Train people on how to add value on local energy sources ( )

d. Integrate energy services into public extension services ( )

e. Ease access to energy alternatives through friendly loans services ( )

f. Other (Specify) ____________

Appendix 2: FGD Guide

Research on:

Availability, Accessibility and Value-Addition Dynamics of Biomass Energy Options Within Rural Households in Navakholo Constituency, Kenya

1. How has land use changed over the years (1990- 2020) based on indicators below?

	Food crops	**Sugarcane**	**Tree cover**
1. Increased			
2. Decreased			
3. Remained the same			
4. Not sure			

2. How would you rate availability of wood fuel through the same period?

Has increased	**Has declined**	**Remains the same**	**Not sure**

3. What comes to mind when you consider the status of tree cover in households in your community? (Brain storm and rank the opinions; and have a note book for recoding responses)

4. What is the general trend of wood fuel availability through the year?

Scale: 4=very sufficient, 3=sufficient, 2=scarce, 1=very scarce

Jan	**Feb**	**Mar**	**Apr**	**May**	**Jn**	**Jy**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**

5. Explain the main effects of firewood shortages (Brainstorm and rank the effects in a note book)

6. What interventions are commonly used to ensure that firewood supply is guaranteed? (Brainstorm and rank the interventions in a note book)

7. Apart from firewood, how else do most households try to ensure ready supply of energy for domestic use (Brainstorm and rank the interventions in a note book)

8. How popular are the following interventions in energy supply and use in households?

4=very popular; 3=popular; 2=not popular, 1=not seen any

Interventions	**5**	**4**	**3**	**2**	**1**
1. Charcoal					
2. Biogas*					
3. Dung-soil balls					
4. Saw dust balls					
5. Briquettes*					
6. Improved cook stoves*					
7. Gas (LPG)					
8. Grid electricity					
9. Solar energy					

* if responses 2 and 1 are dominant, ask why?

9. How else do households **manage** firewood and other biomass sources to ensure adequacy of supply and use efficiency? (Brainstorm and record value-addition aspects and their rationale)

10. Going forward, what should be done to ensure sustainable household energy supply

Appendix 3. Environmental Checklist Template

(Tick where Appropriate)

SECTION A: Status of Tree Coverage at the Household

1. Presence of trees
a) Yes ( )
b) No ( )
2. Tree cover pattern
a. Woodlot ( )
b. Planted along the fence ( )
c. Scattered in compound ( )
d. Other____________________________
3. Type of trees in homestead
a. Indigenous ( )
b. Exotic ( )
4. Tree species ________________________________
5. Evidence of tree management practices
a. Pollarding ( )
b. Coppicing ( )
c. Pruning ( )
d. Thinning ( )
e. Other __________________

SECTION B: Biomass Use and Management

6. Type of biomass available
a. Firewood ( )
b. Charcoal ( )
c. Cow dung ( )
d. Saw dust ( )
e. Biogas slurry ( )
f. Agricultural by-products e.g. maize cobs, husks, pulp and stubble ( )
7. Type of cooking device in use
a) Traditional stove ( )

b) Improved Cook Stove ( )

c) Gas ( )

d) Other___________

8. Storage area

a. Yes ( )

b. No ( )

9. Explain the type of storage ______________________________

SECTION C: Value Addition at the Market Place

10. Presence of biomass- based value added products in the market

a. Yes ( )

b. No ( )

11. If yes, identify the type of product

a. Briquettes ( )

b. Energy balls ( )

c. Others__________________

12. How was biomass in the market handled/marketed?

a. Bulk as it is ( )

b. Split into pieces ( )

c. Packaged ( )

d. Other____________________

Appendix 4: Biomass Value Addition Tool

Respondent No.   Sex: Occupation

Highest level of Education: ……………………………………

1. Type and source of biomass available (Tick as appropriate)

	Forest reserve	Own farm	From distributors	Free off-farm sources	Local purchase
Firewood					
Charcoal					
Briquettes					
Cow dung					
Saw dust					
Biogas slurry					
Agricultural by-products like husks, pulp, stubble					

2. How do you manage your biomass to ensure continuous supply and benefits? (Tick accordingly)

	Fire wood	Biogas	Briquettes	Husks etc.	Dung	Saw dust	Charcoal dust
Pollarding							
Coppicing							
Pruning							
Regular re-planting							
Dry storage							
Chopping to fit cooking facility							

Extinguishing after cooking							
Selling specific weights or sizes							

3. Where do you take the biomass at your disposal? (Tick as appropriate)

	Own farm use	Sell to neighbours	Sell at local markets	Abandon to own fate	Collect and dispose
Firewood					
Charcoal					
Briquettes					
Cow dung					
Saw dust					
Biogas slurry					
Agricultural by-products like husks, pulp, stubble					

4. How else do you use the following biomass types? (Tick as appropriate)

	Make briquettes	Make single energy balls	Make combined energy balls	Compost to manure	Bulk and sell as it is	Burn on site	Abandon it to own fate
Cow dung							
Saw dust							
Biogas slurry							
Husks & pulp							

Stubble and maize cobs							

5. Who are the **main buyers/users** of biomass energy sources?

	Households	Schools	Restaurants	Traders	Local factories (Brick makers)	Government agencies e.g., KPLC, Telcom
Firewood						
Charcoal						
Briquettes						
Cow dung						
Saw dust						
Biogas slurry						
Husks and pulp						
Stubble and maize cobs						

6. What challenges do you encounter when dealing in biomass and its by-products?

	Major	Minor	Inconsequential
Government restrictions			
High market taxes and levies			
Handling due to bulkiness			
Weather related			

Limited availability/poor supply chain			
Storage			
Processing into new products			
Transportation			
Occupation safety and health risks			
Competition from alternative energy sources			

7. Any other final comment:

Appendix 5: Interview schedule for Key Respondents

1. What factors influence access to biomass?

   ____

2. Are there challenges with regards to availability and access biomass?

   ____

a. Yes

b. No

   If yes, explain

   ____

3. In your view what strategies have been used for value addition among biomass-based energy options within the county?

4. How can we add value to biomass firewood, charcoal with regards to the following?

a. Harvesting

b. Collection

c. Transportation

d. Pre treatment

e. Storage

f. Handling

5. What initiatives are in place to promote sustainable use of biomass at:

a. The county____

b. Household____

6. What is your view in regards to the adoption of ICS?

7. Has there been an enabling environment to support the adoption of alternative energy sources?

a. Yes

b. No

8. Are there challenges in the implementation and adoption of alternative energy initiatives within the county?

a. Lack of supportive policies

b. Distribution costs

c. Capital costs

d. Social acceptability

e. lack of availability of materials

f. lack of extension services

g. other________________

9. What are the opportunities for the adoption of alternative energy sources within the sub-county?

10. In your opinion, what are the threats to tree cover within the county?

    ____

Appendix 6: Research permit

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

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NACOSTI, Upper Kabete
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NAIROBI-KENYA

Ref. No. **NACOSTI/P/19/05622/30871**

Date: **7th June, 2019.**

Stacey Nawanjaya Wando
Kenyatta University
P.O. Box 43844-00100
NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Accessibility and quality of biomass based energy options among farm households in Kakamega County, Kenya."*** I am pleased to inform you that you have been authorized to undertake research in **Kakamega County** for the period ending **6th June, 2020.**

You are advised to report to **the County Commissioner, and the County Director of Education, Kakamega County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

BONFACE WANYAMA
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Kakamega County.

The County Director of Education
Kakamega County.

National Commission for Science, Technology and Innovation is ISO9001:2008 Certified