COMMERCIALIZATION OF AGRICULTURAL WASTE BRIQUETTE AND CHARCOAL PRODUCTION TECHNOLOGIES IN BARINGO AND NAKURU COUNTIES, KENYA

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Master of Science Degree in Agri-enterprise Development of Egerton University

EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not, wholly or in part been presented in this University or any other for the award of a degree.

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Recommendation

This thesis has been submitted with our approval as University supervisors

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DEDICATION

This thesis is dedicated to my lovely family, mother, brother and sister. Special dedication to my younger siblings to remind them that anything is possible as long as you set your mind to it.

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ABSTRACT

The bulging country's population, rising environmental concerns and high cost of alternative energy sources has resulted in an increased demand for biomass energy. Several improved technologies have been developed in a bid to meet this demand and disseminated across the country, but the lifespan of such technologies rarely goes beyond the project period. The general objective of this study was to contribute towards climate change mitigation through promotion of climate smart entrepreneurship in Baringo and Nakuru counties. Specifically, the study: (i) evaluated the economics of investment in different Egerton university briquette and charcoal production technologies among SMEs in Baringo county; (ii) analysed the willingness to pay for briquettes, as an alternative source of energy, among Nakuru urban residents; (iii) determined the pathway for commercialization of bioenergy technologies and products among stakeholders in the charcoal and briquette value chain. A multistage sampling technique was used to sample 384 household respondents in Nakuru County and data collected using semi-structured questionnaires and choice cards. Purposive sampling was used to select 75 entrepreneurs from Baringo county, and 5 key informants and data collected using focus group discussions and interviews respectively. Data was analysed using mixed logit model, cost-benefit analysis and thematic content analysis. Investing in improved charcoaling and briquetting technologies was found to be economically viable with all the technologies yielding positive net present values (NPV) with short payback periods. The highest NPV was recorded from drum agglomerator for briquettes production and vertical drum kiln for charcoal production. The Payback Period for all technologies ranged between 1-1.95 years, meaning that it will not take a lot of time to get returns on investment. Households showed less preference to briquettes which produced smoke with a negative coefficient of -0.909 at 1% level of significance. This indicates that households are more cautious about the health implications than other attributes. The findings also indicated that market, economic, technical and policy barriers influenced the commercialization of bioenergy technologies and products. The study provides recommendations on how to improve the design of briquette/charcoal production technologies to make them user-friendly and suggests mechanisms for wide-scale commercialization of the technologies in the country. The study suggest that the government could invest more in the renewable energy sector by encouraging public-private partnerships to attract more attention from those who would wish to get into bioenergy business

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LIST OF ABBREVIATIONS AND ACRONYMS

ASALs:	Arid and Semi-Arid Lands
CSE:	Climate Smart Entrepreneurship
CST:	Climate Smart Technology
CVM:	Contingency valuation method
DCE:	Discrete Choice Experiment
EUBT:	Egerton University Bioenergy Technologies
FAO:	Food and Agricultural Organization of the United Nations
GHG:	Greenhouse Gas
GoK:	Government of Kenya
ICRAF:	International Council for Research in Agroforestry
ICSU:	International Council of Scientific Unions
KCSAP:	Kenya Climate Smart Agriculture Project
KEBS:	Kenya Bureau of Standards
KES:	Kenyan Shilling
KFS:	Kenya Forestry Service
KNBS:	Kenya National Bureau of Statistics
MCRC:	Shri AMM MurugappaChettiar Research Centre
MEWNR:	Ministry of Environment, Water and Natural Resources
NEDAP:	Neighborhood Economic Development Advocacy Project
NIB:	National Irrigation Board
R&D:	Research and Development
SDGs:	Sustainable Development Goals
SMEs:	Small and Medium Entrepreneurs
SSA:	Sub-Saharan Africa
IRR:	Internal Rate of Return
NPV:	Net Present Value
PP:	Payback Period
UNDP:	United Nations Development Program
WTP:	Willingness to Pay

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Biomass is a renewable energy source derived from plant material including wood, charcoal or agricultural by-products which are burnt for heating and cooking (Agyemang *et al*., 2021; Helal *et al*., 2023) Biomass energy has contributed substantially to meeting the rapidly growing demand for energy globally (Kundu *et al*., 2018) and regarded as a more sustainable energy source than fossil fuels (Al-Bawwat *et al*., 2023). In Kenya, the commonly used sources of energy are firewood and charcoal. Approximately 3 billion people depend on wood as the prime energy source for domestic use (Muazu & Stegemann, 2015). Overreliance on wood fuel as major source of household energy has facilitated rapid increase in environmental degradation especially in rural communities (Jewitt *et al*., 2020). This has led to a concerning decline in forest land, exacerbating climate change as deforestation releases significant amounts of greenhouse gases into the atmosphere (Joseph & Kaswamila, 2017).

With the increasing dependency on wood fuel as the major energy source for the rural communities, the effects on forest land continues to aggravate, and the health of the people being compromised. Any mitigation measure that would ensure reduction in the use of forest trees as a source of energy is important (Mutugi, 2015). Baringo is one of the counties in Kenya with numerous charcoal entrepreneurs. There is need to develop technologies that would ensure charcoal is produced sustainably ensuring good health and environmental protection (Hamid & Blanchard, 2018).

Charcoal in Baringo is produced from *Prosopis juliflora* (Mathenge) and *Acacia tortilis* (Umbrela thorn) which are preferred for their ability to burn for a longer period (Dato *et al*., 2019), making Baringo charcoal more marketable in urban areas like Nakuru. Approximately 97 percent of the households that practice charcoal production majorly use earth mound kilns (Mieke *et al*., 2020). These are in most cases inefficient and produce a lot of smoke that increases the levels of air pollution. A lot of time is also spent in making these kilns, while the returns still remain low. The producers sell to urban centres around Baringo like Nakuru while some sell as far as Nairobi. With demand exceeding supply, there is rise in production of charcoal which comes with negative effects as noted by Korir (2019), such as respiratory diseases, lung cancer as a result of prolonged exposure to indoor pollution. This creates the need to produce charcoal more efficiently and sustainably. Egerton University has developed technologies that will ensure that charcoal is produced in a manner that will minimize carbon emission, reducing the time spent in burning charcoal and reducing the quantity of wood used in making charcoal. These are Vertical Drum Kiln and Horizontal Drum Kiln as shown in Appendix F. These carbonation technologies are able to produce clean charcoal through the pyrolysis process (a process that involves heating of an organic material like biomass in a limited oxygen supply), minimize carbon emission by condensing the smoke into wood vinegar and produce biochar which is an excellent soil ameliorates (Aziz *et al*., 2023; Zama *et al*., 2018).

The increase in efficiency of charcoal production ensures that charcoal is produced fast, and this could be a better way for controlling the *Mathenge* tree which has become an invasive weed in the region. The invasion has resulted in the loss of natural biodiversity, reducing the land coverage for agriculture and grazing (Mbaabu *et al*., 2019). The tree species has also led to obstruction of water sources in the region as well as increasing farming costs as farmers incur labor costs to clear the invaded cropping land (Eschen *et al*., 2021). Reduced underground water availability has also been noted as a problem caused by the species invasion (Dzikiti *et al*., 2013; Linders *et al*., 2019). Promoting efficient technologies in the region would therefore ensure better utilization of the tree.

Biomass briquettes production is an effective way to achieve clean and sustainable energy which in turn would enhance the promotion of Climate Smart Entrepreneurship (CLE), that is, those innovations and businesses that utilize the natural resources effectively and promote environmental conservation. Human activities will ultimately cause harm and there is need for urgent control of these, which can only be realized through sustainability (Gast *et al*., 2017). Climate Smart Entrepreneurs will not only be successful in creating economically profitable business models but also those which are conscious of the environment. In Baringo county, charcoal still remains an important source of energy, livelihood and income. Many small and medium enterprises (SMEs) still continue to grow through the production and trade of charcoal, though a lot of wastages occur along the value chain such that so much charcoal is wasted in the form of charcoal dust. Briquette uses charcoal dust and thus promotes a form of cyclic economy in which waste products are used as raw material to produce a more useful product. It also uses locally available agricultural wastes such as rice husks, coconut husks, corn cobs, waste papers and plant residues as raw materials which would greatly reduce reliance on wood as the major source of fuel.

Biomass briquette presents an opportunity for cheap and clean energy producing quality fuel, generating income and creating employment opportunities especially for the youths (Vivek *et al*., 2019). It also provides an alternative to firewood, charcoal or cooking gas, by enhancing the provision of clean fuel that contributes to reduced air pollution, time wasted collecting firewood, and even cost of fuel as it is cheaper than charcoal. Egerton University has also developed technologies for briquetting which have been disseminated to various SME groups in Marigat and Eldama Ravine constituencies. These are Drum Agglomerator and Screw Press as shown in Appendix F. Establishing briquetting and charcoaling technologies, in the region will not only create opportunities to venture into sustainable agribusiness but also enhance the efforts in creating a green economy, which would be an effective way of promoting Climate Smart Entrepreneurship and improving the income levels of the SMEs in Baringo and other counties by extension. It will also provide clean and safer energy sources to numerous consumers.

1.2. Statement of the Problem

The need to create a sustainable energy industry has resulted in different stakeholders developing technologies that would ensure actualization of this goal. The goal is not only to achieve energy sustainability but also to enhance energy access, reduce greenhouse gas emissions, and foster economic growth, especially in underdeveloped and developing regions. However, realizing this vision requires coordinated actions, investments in research and development, supportive policies, and collaboration across different sectors to overcome any barriers that may hinder the realization of energy secure economies. Egerton university has developed energy efficient charcoaling and briquetting technologies which have been piloted among selected SMEs in Baringo county. The technologies are regarded as climate smart since they are able to increase productivity by producing high quality charcoal and briquettes and also contribute to reduced greenhouse gases emission. Despite the introduction of the technologies, there is limited information on the economics of the technologies for charcoal and briquettes production. Further, the products of the technologies, especially briquettes, its acceptance among users especially in urban households is not clearly established. With the technologies still being at infancy stage, the pathway towards full scale commercialization is still not clear among the stakeholders. Hence, this study aimed at filling this knowledge gap through an exploratory study among stakeholders in the briquette and charcoal value chain in Baringo and Nakuru counties.

1.3. Research Objectives

1.3.1. General Objective

The general objective of this study was to contribute towards climate resilience through promotion of climate smart entrepreneurship in Baringo and Nakuru counties.

1.3.2. Specific Objectives

i. To evaluate the economics of investment in different Egerton university briquettes and charcoal production technologies among SMEs of Baringo county
ii. To determine the willingness of Nakuru county urban residents to pay for briquettes as an alternative source of energy in Nakuru County.
iii. To determine the pathways for commercialization of bioenergy technologies and products among stakeholders in the charcoal and briquette value chain in Baringo and Nakuru counties.

1.4. Research Questions

i. What are the economic implications of investing in various Egerton University briquette and charcoal production technologies among SMEs in Baringo County?
ii. What is the willingness of urban residents in Nakuru County to pay for briquettes as a clean
iii. What are the commercialization pathways for bioenergy technologies and products among stakeholders in the charcoal and briquette value chain in Baringo and Nakuru counties?

1.5. Justification of the Study

The bioenergy sector plays a vital role in overcoming the obstacles associated with increased use of fossil fuels. The sector provides an opportunity to attain reduced carbon gases emission and sustainable energy supply thus contributing to SDG7 (access to affordable, reliable and sustainable energy for all) and SGD13 (combating climate change and its impacts). The Kenya Climate Smart Agriculture Strategy 2017-2026 estimated that the Kenya’s Greenhouse Gas (GHG) emissions would rise from 73 million tons of carbon dioxide equivalent in 2010 to 143 million tons by 2030 if appropriate mitigation measures are not put in place (FAO, 2017). It is therefore imperative that measures that would reduce greenhouse gases emissions be put in place not only to control climate change but also to improve the lives of all. The traditional charcoaling means have proven to be harmful to the environment, even though charcoal remains an important energy source and a source of livelihood to several communities.

Briquettes use has been noted to be environmentally friendly and uses readily available raw materials which can easily be obtained by the SMEs. To revolutionize the bioenergy value chain, the upcoming and existing innovations have to be commercialized in order to reach the wider market since commercialization of innovations is a key to entrepreneurial success. The technologies disseminated have to reach a wider population to have a considerable impact. This study sought to analyse the different opportunities that are existing for these technological innovations to extensively spread among stakeholders.

1.6. Scope and Limitation of the Study

The assessment was limited to Egerton university technologies that had been disseminated to various SME involved in charcoal or briquette production in Baringo county. The economic assessment was done at farm level. The briquette attributes were not considered as independent variables in the analysis of WTP. However, the attributes were used to describe the briquettes during choice experiments based on literature review. This was because most of the variables require lab tests to measure, and with study time frame, this was not possible. The study only covered Baringo and Nakuru counties since Baringo was the target county for the KCSAP while Nakuru was considered the closest big city where Baringo charcoal was marketed.

1.7. Operational Definition of Terms

Bioenergy: is a form of renewable energy derived from organic materials, which includes plant and animal matter such as wood, crop residues, manure, and organic waste

Biomass briquettes: A compacted form of energy produced by applying pressure on biomass wastes with the aid of briquette making machines

Climate smart entrepreneur: a person who has the ability to start an economically profitable business that is conscious of the environment.

Climate smart entrepreneurship: the ability to innovate and start a business model that utilizes the natural resources effectively and promote environmental conservation

Circular bio-economy: an economic model that emphasizes the use of biomass focusing on minimizing wastes and replacing continued use of non-renewable fossils.

Agricultural waste: refers to the by-products and residues generated from agricultural activities

CHAPTER TWO

LITERATURE REVIEW

2.1. Bioenergy Supply and Demand in Kenya

The Kenyan biomass fuel industry dominates the energy sector providing nearly 68% of the total energy required in the country as well as 98% of the rural household energy requirement (Iiyama *et al.*, 2014; Mugo & Gathui, 2010). Charcoal and woodfuel makes up to 70% of the total biomass energy sources that are required for heating and cooking (Karekezi *et al.*, 2006). Studies show that approximately 7.2 million households in Kenya use biomass as the main energy source with charcoal making up to 13.3% and woodfuel 68.7% (GACC, 2016; Wiesmann *et al.*, 2016). Only a small fraction of the Kenyan households uses alternative energy sources like paraffin, liquefied petroleum gas (LPG) and electricity for cooking and heating which is approximated at 1.6 million households (Wiesmann, 2016). Nearly 45% of the total biomass energy resource is from the forests and woodlands which takes approximately 7% of the country's land (MEWNR, 2013). The remaining biomass is provided by the farmlands which also provides agricultural crops and animal wastes (Kiruki *et al.*, 2016). The country's supply and demand for bioenergy has not been consistent over the years causing wood supply deficit every year. For instance, in 2010, the country was noted to be wood deficient by an approximate 10.3 Mm^3 of wood (Iiyama *et al.*, 2014). This is expected to rise by 2032 which will hike the deficiency of woodfuel and charcoal to 18.3% and 19.1% respectively.

The decrease in bioenergy supply levels can be attributed to aspects such as inefficient fuel sources, increasing agricultural production which has increased the conversion of forest lands into agricultural lands and conversion of forest land into human settlements (Drigo *et al.*, 2015). The hastily increasing bioenergy demand, however, has been attributed to the bulging country's population, over-dependence on woodfuel as the primary source of energy, lack of efficient production technologies across the whole bioenergy value chain (GoK, 2015). The imbalance between the bioenergy supply and demand has resulted in continued degradation and overexploitation of the forest lands which has resulted in increased greenhouse gases emissions (Nyambane *et al.*, 2014). It is in this context of rising bioenergy demand and decreasing supply that more efficient production techniques are promoted in Kenya and alternatives adopted to supplement the already available energy sources to meet the requirement.

2.2. Bioenergy Climate Smart Enterprises in Africa

There is a growing concern about the impacts of climate change on agriculture, food security, energy demand and poverty globally. Climate change adds to the many challenges facing rural development in Africa (Maggio & Sitko, 2019). Utilizing the potential of innovation especially in the vulnerable communities gives poverty reduction an entrepreneurial approach. Climate smart entrepreneurship innovations require not only financial investment but also social and natural capital investment (Dey *et al.*, 2019). This would help boost the capacity of communities or individual entrepreneurs to easily transform the resources they have into enterprises with the available technologies. Energy plays a key role in economic development of African countries. The bulging Sub-Saharan Africa population will require improvement in the energy system if poverty is to be addressed effectively (Ambali *et al.*, 2011). The rural populations are more affected by poverty, and this should not be taken as part of the course if poverty reduction is to be addressed in Africa.

Improved innovative technologies in the bioenergy system will not only address the issues of efficiency in the value chain but also act as poverty alleviation tool in the rural communities. The Sub-Saharan African countries could take advantage of the existing biomass potential to enhance concentration in agriculture to reinstate the rural capacities which would address various socio-security problems giving a new look to the bioenergy potential. Approximately 80% of African countries still depend on woodfuel like charcoal and firewood as the major source of energy (Jewitt *et al*., 2020) which in most cases is produced inefficiently with less returns (Cotula *et al*., 2008; NEPAD, 2005). A larger portion of the African population is faced with energy insecurity even as dependency on wood as the prime source of energy continue to accelerate (ICSU, 2007). There also exists a variation in the availability of cleaner energy sources between the urban and rural communities.

The pursuit to develop alternative options to non-renewable energy forms has gained momentum triggered partially by global rise in fossil fuel prices and uncertainties surrounding power utilities in Africa (Jumbe *et al*., 2009; Surroop & Raghoo, 2018). There is a rejuvenated attention on the bioenergy for their ability to reduce greenhouse gas (GHG) emissions, supplement the available energy forms, increase farmers' returns by utilizing crop residues for additional income, creating new employment opportunities and generally improving rural economic development (Meyer *et al*., 2008). The growth of many African nations particularly with reference to producing cheap, clean and sustainable energy depends mainly on the accessibility of the energy sources (Jain & Jain, 2017; Shane *et al*., 2017).

African countries are rich in bio-resources that can easily be converted to clean energy apart from other renewable energy sources like wind, solar and hydro. There exist numerous plant species that can be utilized to produce eco-friendly energy. This has pushed for production and demand for sustainable bioenergy in the region (Rahman *et al*., 2017). The quest entails energy forms like biodiesel, bioethanol, biogas and briquettes which are majorly produced from agricultural raw material or residues using cheap and easy to make technology innovations (Mungwe *et al*., 2016). Some of the bioenergy forms have been commercialized while others still struggle with breaking the acceptability barrier among the consumers. The management of these bioenergy forms will not only change the face of the bioenergy value chain in Africa but also improve the productivity of the agricultural sector as most of the raw materials used are obtained from agricultural residues (Estoppey, 2010; Owamah *et al*., 2014a). This will also create job opportunities among the many unemployed communities while ensuring environmental sustainability.

The scattered sort of some African populations may not allow for a network and a continuous supply of energy sources like electricity which may be quite expensive (Muller, 2007; Owamah *et al*., 2014). The expense that comes with such sources of energy has built a momentum to invest in and produce cheaper and sustainable energy forms in communities (Efoevboknan *et al*., 2018). Even though the alternative sources of energy like biogas may require some technical know-how, the economies of investing in them are quite cheaper as compared to electricity and LPG. The development of bioenergy sources is thus an efficient way of promoting clean, affordable and sustainable energy sources in Africa. Investing in bioenergy forms not only help combat the menace of energy insecurity especially among the rural African population but also a way to increase household revenue streams. It also gives an opportunity to not only reduce greenhouse gas emissions but also utilize agricultural waste products into more useful products. This provides an entrepreneurial concept to the bioenergy value chain.

2.3. Energy Climate Smart Technologies

The United Nation (UN) Sustainable Development Goal 7 adopted in 2015 envisioned a global economy with safe, affordable and sustainable energy supply which would raise the bioenergy portion in the world's energy blend (UN, 2015). Energy contributes the largest percentage, approximately 60% of the world's greenhouse gas (GHG) emissions impacting climate the most with over 40% of global population depending on inefficient cooking fuels (UNDP, 2015). Traditional biomass (woodfuel, charcoal, agricultural wastes, dung) accounts for the largest share in the global energy mix yet most of it is produced inefficiently (Khatiwada *et al*., 2019). This has resulted in a rapid bioenergy demand which is also exaggerated with the increasing population. As a result, more pressure is put on the forests increasing the rate of deforestation and consequently the impact of climate change.

The increased use of conventional biomass has also been associated with increased health problems among the rural communities which rely on it as the major source of energy. Incomplete biomass combustion releases smoke particles and carbon monoxide (CO) which are harmful to the health of the producers as well as the users. The combustion process is a serious cause of carbon emission into the atmosphere, jeopardizing the air quality, compromising health of the people and consequently adding on to the causes of climate change (Chen *et al*., 2017). There is therefore a need to shift from the traditional bioenergy combustion methods to improved, modern bioenergy production methods, not only to increase energy security but also enhance economic development of the rural communities like Baringo.

Most of the biomass used in Kenya is obtained from farmlands, forests, or woodlands. Biomass energy is then produced and utilized conventionally with the use of inefficient and unsustainable technologies which result in increased demand for wood from the already diminishing forest covers. This has attracted global concerns as awareness on climate change and energy insecurity rise. Wood is a major raw material for the manufacture of charcoal among the charcoal producing communities like Baringo. Several industries: agro-processing industries, brick making industry, also rely on wood as an important source of energy (Githiomi *et al*., 2012). There is need to promote those technologies that would reduce reliance on wood as the major raw material in the production process or rather technologies that would offer better utilization of wood to reduce the amount of wood being used in the production processes.

2.3.1. Charcoal Production and Technologies

Kenyan charcoal production is done in remote areas where wood is obtained mainly from individual farms (ICRAF *et al*., 2020). Charcoal value chain analysis carried out in 2018 showed that charcoal is produced mainly through earth mound kilns (Ndegwa *et al*., forthcoming). These inefficient technologies need to be improved if pressure on the forests is to be reduced. Njenga *et al*. (2013) and Njenga (2013) say that Kenya stands out as the largest charcoal consumer in Eastern and Southern Africa with Nairobi being the leading consumer in the country. The highest amount of charcoal consumed in Kenya is from the ASALs (Burrow & Mogaka, 2007; GoK, 2018; Iiyama *et al*., 2014;) which is approximately 70% of the country’s total production. 50% of the total wood extracted from the forests is used as fuel with charcoal taking up 17% of the wood (FAO, 2016a). Brazil leads in charcoal production globally

(FAO, 2016d), while Africa heads the charcoal production industry, supplying 62% of the world's charcoal with Nigeria topping the list (FAO, 2017).

In a study conducted on Kenya's woodfuel and trade flows, it was noted that charcoal wood is obtained from different sources with 86% of wood obtained from private farms (Mutimba & Barasa, 2005; Ndegwa *et al*., 2020). The choice of a tree species used for charcoal production depends on the tree availability and the charcoal quality produced. In dryland areas like Baringo, *Acacia spp* is the predominant tree species that is characterized as a hardy, dense tree with minimum moisture content thus becoming a good option for charcoal production (Mutiti 2010; Njenga *et al*., 2013). These features make acacia tree the most preferred charcoal wood as noted by Oduor *et al.* (2012). A study by Friederich (2016) showed that charcoal produced from acacia trees contains a very high calorific value of 8000kcal per unit kg as compared to those from trees such as bamboo (6900kcal per kg) or teak (6500-7000kcal per kg). *Prosopis juliflora* (Mathenge) is also an outstanding tree species used for charcoal production in Baringo county, particularly Marigat constituency. Introduced in 1980s, the tree species has so far been invasive spreading across the county covering approximately 640 hectares of land per year (Mbaabu *et al*., 2019). The invasion has caused land degradation, covered grazing land and interfered with human settlement in Baringo. In a study conducted by Ndegwa *et al*. (2019), Mathenge tree has been ranked the number one source of wood for charcoal production in Baringo county with 80% of the charcoal producers relying on it for production. Improving technologies aimed at better utilization of the Mathenge tree will enhance livings and the environment (Mbaabu *et al*., 2019).

Kenya's charcoal production is done largely by small and medium producers scattered in numerous locations especially around forests and shrub lands of the nation. Even with the ban enacted in 2018, production continues de facto as demand and supply continues to rise especially in urban regions. The preference for charcoal continues to rise for its low cost and long-life storage compared to other energy sources like LPG and electricity (Ndegwa, 2016). Unlike LPG and electricity, charcoal can be obtained in small and affordable quantities as per the consumer's preference while the cost of other sources like kerosene which could be used as a substitute is inconsistent (Bailis, 2005). This industry is very significant as an important source of fuel energy and a source of livelihood to the many SMEs that are involved. With the growing unemployment rate, the sector creates an important revenue opportunity for many citizens.

There exist various types of kilns used charcoal production, including traditional earth kiln, improved earth kiln, casamance kiln, brick kiln, steel kiln and retort kiln. The most used kilns in Kenya and the rest of Sun-Saharan Africa (SSA) are the traditional earth kiln, improved earth kiln and the casamance kiln. Mutimba and Baraza (2005) note that 99% of Kenyan charcoal producers and 100% of Baringo county producers (Ndegwa *et al*., 2021), mainly rely on the traditional kilns for their production which are inefficient yielding less output in relation to the amount of biomass invested. Nevertheless, the quality of charcoal produced, and the efficacy of the charcoal is subject to wood type used which is determined by its moisture content, kiln used, the manner in which the wood is stack, the quantity of wood in the kiln and the expertise of the producer (FAO, 2017).

Traditional earth kilns are commonly used by small producers with an efficiency of 15-20% taking approximately 5-10 days for complete carbonization (Oduor *et al*., 2006; Ruuska 2012). Most charcoal producers prefer the traditional earth kilns for their cost. A lot of wood material is used as the carbonation process tends to be slow. The Traditional earth kiln uses wood usually 1-2m logs arranged in a semi-conical or trapezoidal prism shape on a level ground (Bailis 2017; KFS, 2013; Mutimba & Barasa, 2005). Twigs are used to cover the stack and aid in the burning process when lighting which is then covered by grass as well as soil then ignited (Ndegwa, 2020). The improved earth kiln/casamance is also common among small scale charcoal producers but contrary to the traditional earth kiln, they have chimneys which ensure air flow during the burning process increasing efficiency to 26-30% (Oduor, 2006). These, however, need a lot of accuracy, especially in lighting which makes them less preferred by the producers.

2.3.2. Biomass Briquette Production and Technologies

The characteristics of briquettes majorly depend on the type of raw materials used in terms of feedstock and binders. The type of material used is based on the geographical area which would determine the material availability, the area climate and the agricultural residue (Orhevba *et al*., 2016). The main sources of biomass briquettes in East Africa (EA) are maize cobs and wheat husks. These agricultural residues are normally discarded as wastes, while others left to decompose to add on to the soil humus and a good amount burnt which produce smoke particles and carbon monoxide adding increasing the amount of GHG in the atmosphere (Okoko *et al*., 2017).

Briquettes production presents as opportunity to transform the bioenergy value chain since it produces clean energy with long burning capacity. This could transform the energy system into a sustainable sector. Muaza and Stegeman (2015), in their study note that biomass briquettes have high heat resistance, low moisture content and higher flame temperatures. Biomass briquettes also have higher calorific value, lower ash content, reduced smoke with less soot (Vivek *et al*., 2019). The same features are also noted by Ndindeng *et al*. (2015) including higher volatility with magnificent combustion properties. The production of briquettes involves three main stages: a) milling which involves chopping the feedstock into small pieces b) carbonation where the biomass feedstock is converted into biochar burnt in low oxygen concentration c) the biochar is then mixed with binders like molasses and put into the briquetting machine to produce briquettes which are then dried for use (Damien *et al*., 2010; Suprianto *et al*., 2018).

The major raw materials for briquetting are agricultural and forestry biomass which are compressed and bound to form briquette. The biomass raw materials are compressed under high temperatures. The process requires compressing machines to exert pressure on the materials to get a component (briquette) that is dried and used for cooking or heating. Current machines for briquetting in the market include piston press, manual press, rotter press including some homemade pressers (Aliyu *et al*., 2020; Kaosol, 2011). Briquettes are produced from cheaply available agricultural residues like maize cobs, rice husks, saw dust chippings, charcoal dust, bean straw, groundnut shells, coconut husks among other agricultural by-products including forest twigs. The binders could be molasses, maize starch, gum Arabica which could be added in a 2 percent ratio to the biomass feedstock of 85% and 8 percent water (Mugo, 2013; Ndegwa *et al*., 2020). The binders are used to hold the briquettes together which depends majorly on the moisture content and the efficiency of the machines. The feedstock has to be dried to 13% moisture content enabling the feedstock to be chopped into pieces that can be easily utilized by the machine (Amer, 2014). This is also done to make the binders mix easily with the raw materials. A 3:1 ratio mixture is recommended for feedstock and binders respectively and the same ratio for water to feedstock respectively (FAO, 2018). The mixture is then fed into the machine, which is then compressed into briquettes, shaped depending on the type of machine. This is then dried under the sun and ready for use (Korir, 2019; Petrov, 2011).

Even though the country is making significant efforts to improve the energy value chain, for instance, investing in renewable energy sources like geothermal, wind and solar energy, the charcoal industry continues to thrive with the rising energy demand (MEWNR, 2013). These studies also note that the sector supports over one million citizens, denoting its importance in the country. *Prosopis juliflora* which threatens the environment and the rural livelihoods (Mbaabu *et al.*, 2019; Mooney, 2005) has been noted to produce high quality charcoal (Oduor & Githiomi, 2013). The tree species was rated as the best charcoal producer among other tree species in a survey done in 2019, in Baringo (Njenga *et al.*, 2019). Mbaabu *et al.* (2019) also recorded in his studies that taking advantage of the species' invasion and using improved technologies to produce charcoal from it would improve economic lives of the people as well as maintaining the environment. There has been limited use of modern and improved technologies in the production of charcoal. For example, Wanjala (2016), notes that the improved Drum kilns disseminated by KFS were only bound in Mwatete sub-county. Baringo county, which is the study area, uses mainly the traditional kilns for charcoal production (Ndegwa *et al.*, 2021).

Uptake of and investment in improved technology is dependent on the technical know-how of the producer, the set-up cost and the ease of movement of the technology (Kiteka *et al.*, 2017). There is therefore a need for a detailed approach to meet the ever-rising energy demand, improve the livelihoods of both producers and consumers and protect biodiversity. A qualitative and monetary approach is thus suitable in analysing the economies of investment in improved technologies for production of charcoal and briquettes.

2.3.3. Egerton University Bioenergy Technologies (EUBT)

Egerton University has developed various Climate Smart Bioenergy Technologies which have been disseminated to various charcoal and briquette producer groups in Baringo county. These include Screw Press and Drum Agglomerator, both for briquette making and Vertical Drum Kiln, and Horizontal Drum kiln, for charcoal production as shown in Appendix F. Through the KCSAP Bioenergy Value Chain Project in Baringo, the university anticipates helping mitigate the effects of climate change through the use of improved charcoal making technologies, shifting the community from the conventional charcoal making methods which have highly resulted to increased carbon emission into the atmosphere. The briquette making machines are on the other hand promoted to provide an alternative source of energy which is more efficient and thus help reduce carbon emission to the air. These technologies are assumed to create a revolution in the charcoal and briquette making industry in Baringo and Nakuru not only to help mitigate the energy insecurity but also offer opportunity to reduce environmental pollution, reduce health risks and increase income to the SMEs, which would in turn help achieve the United Nations Sustainable Development Goal 7 on clean, affordable and sustainable energy.

Drum Agglomerator: Agglomeration basically is binding powder particles together in order to increase the particle sizes. Drum Agglomerator is a biomass agglomeration technology that consists of a rotating chamber that is fed with the powder (powdered char) together with a binder to form briquettes. The rotation exerts centrifugal, inertia and frictional forces that aid in the binding of the particles together (Siemons *et al*., 2011). As the rotation continues, the particles come together to form ball-like rolls and with the help of the binder, the size of the particles increases as rotation continues. The briquetting process involves adding the raw materials (powdered char and binders like molasses) into pan. The rotating disc is then turned on and as the disc rotates, the particles bind together into balls. The balls through coalescence grow larger as rotation continues until the briquette is removed at the desired size. Powder-binder mixture will determine the quality of the briquettes (Mort, 2009). Agglomeration is also influenced by feedstock characteristics like the particle size, shape, porosity and rotation time and speed as noted by Mort (2009). Briquettes produced are spherical and the diameter depends largely on the time duration of the process.

Screw Press: This is a briquetting technology that produces high quality briquettes compared to other technologies like the piston press with a briquette density of 1-1.4gm/cm^3. The briquettes produced from this technology are also homogenous which increases its acceptance among its users. The biomass fed into the screw press is extruded by a screw via a heated taper die. Briquettes from a screw press are highly combustible with good storability (Sanap *et al*., 2016). It typically uses auger to press the raw materials. Briquetting requires binders like molasses or any binding material for the desired compactness to be achieved. The biomass is fed to the hopper which is then conveyed into the machine by the screw. The screw which continuously rotates takes the biomass from the feed port and against a die, it is compacted. The end product is briquettes which comes in any shape depending on the design of the press, that is, round, square, plum blossom, cylindrical, etc. The machine is equipped with a heating system for high performance.

Horizontal Drum Kiln: This is an efficient, easy to construct technology that could be appropriate for household charcoal production. The kiln is capable of converting even small tree branches into charcoal beside producing wood vinegar. Any wood material can be used to produce charcoal in the drum kiln. The kiln’s biggest attraction is its ability to convert any type of biomass into charcoal including twigs. This however produces a lot of charcoal dust but if the main aim is production of biochar for briquettes production, then the drum kiln is an appropriate method. The time needed for complete wood carbonization using the kiln depends on the type, size and moisture content of the wood (Kittichai, 2010). The average carbonization time ranges between 2 to 3hours. The kiln produces approximately 12 to 18kg of charcoal for each 60 to 80kg of wood fed into the kiln (Burnette, 2013).

Vertical Drum Kiln: This is a cylindrical portable structure with a chimney attached to it on the side. The drum could be 100cm to 150cm high with about 100cm wide. The body is made up of iron sheets. There are two firing and two exit ports at the lower side of the drum. Just above the firing port, there is a perforated sheet with holes to allow air entry into the biomass. This type of kiln is relatively easier to operate and can easily be managed during carbonation. Its operation time is also lesser compared to other carbonization kilns, producing high char quantity. These qualities make this kiln more preferred for its effectiveness. The carbonization process begins with feeding the appropriately cut biomass into the kiln, where the top is then covered with a metal lid. A drum of 150cm high and 100cm wide can produce approximately 100kg of dry biomass. The biomass is then fired through the firing ports to ignite after which the ports are closed. With low oxygen concentration, the fire spreads slowly to the entire biomass. Carbonization takes from 1 to 3 hours depending on the type and moisture content of the biomass. After carbonization is complete, the exit ports are opened to remove the carbonized material (charcoal). Water is sprinkled over to cool the char.

2.4. Theoretical Framework

The research was based on Strategic Niche Management (SNM) approach. Strategic Niche Management is a recent approach designed to aid in introduction and diffusion of new sustainable technologies through societal experiments. The major aim of SNM is to ensure a more significant, sustainable economic development aided by technological progress and system-wide social-institutional transformation (Elzen *et al.*, 2004; Hoogma *et al.*, 2002). Sustainable development literally aims at creating and maintaining a balance between economic, environmental and social aspects. This not only ensures the present generation’s needs are met but also uncompromised future generations’ needs. Initiating sustainable development that would ensure the balance is a challenging task.

Useful and potentially sustainable technologies in most cases do not go beyond the prototype stage to create a market regardless of how promising their performances are in relation to the existing technologies. SNM helps to give understanding of these challenges creating possible solutions to tackle them. The approach is based on the fact that technologies are part of a complex system called ‘socio-technical regime’. This regime includes scientific knowledge, engineering practices, production processes, technology/product characteristics, skills and procedures, user needs, policy and regulatory requirements, institutions and infrastructure (Hoogman *et al*., 2002). The whole complexity is rooted in a context of material and immaterial societal factors which can only change progressively such as demography, political practices, lifestyle and the economic system (Raven, 2005).

Usually, the existing mature technologies dominate the niche because of their continuous evolution and adaptation to societal factors. The radically new innovations, especially those geared towards environmental and social sustainability do not do so well with the existing socio-technical regime features. They require strong adaptations to successfully develop and diffuse into the market. SNM tries to address this challenge by advocating for a collaborative engagement between all the innovation stakeholders in order to exchange knowledge and experiences that would aid in adoption of the new innovation. The collaboration takes place in a setting called niche which is the initial stage and thus technological in nature. At this stage, even though the technology has admirable features it has not yet fully captured the market. The socio-technical experiments help create a sort of proto-market that helps put the technology in the market space. This is called technology re-construction which helps build market linkages and allows evolution of the technology into the market space (Hoogma *et al*., 2002). It allows the technology to build sustainability in the market. SNM framework plays a crucial role in understanding how new technologies can develop and gain a foothold in competitive markets by providing a structured approach to experiment with sustainable innovations.

In this study, the SNM approach was particularly useful in uncovering the challenges that new technologies face when attempting to commercialize into sustainable enterprises. These challenges include navigating regulatory barriers, securing funding, and gaining consumer acceptance among others. By applying SNM, the study highlighted the critical need for supportive networks, and stakeholder collaboration to test and refine innovations. Ultimately, the SNM framework provides valuable insights into the complexities of market entry and growth for sustainable technologies, helping to guide their successful transition from niche experiments to competitive enterprises.

2.5. Conceptual Framework

Based on the reviewed literature concerning bioenergy demand, the production technologies and the efficiency of these technologies, a conceptual framework was proposed in Figure 2.1. below. Economies of investment in a bioenergy climate smart technology was assumed to be influenced by factors such as (a) resource accessibility and cost, and (b) efficiency of the technology in terms of labour requirement, production time and product quantity. The study considered briquettes as one major product of these technologies. The WTP for briquettes was assumed to be influenced by three factors: a) the product's attributes such as ash content, smoke level, heat value, burning period, ash content and product price, b) the consumer attributes such as consumer awareness and preference, c) and socio-economic factors like age, gender, education level, household size, household income and household decision maker. Investing in these technologies and willingness to pay for their products (briquettes), was assumed to create opportunities for the development of commercial climate smart enterprises (CSE) along the bioenergy value chain which would help improve the sector. The commercialization of these enterprises, however, is assumed to be influenced by barriers such as market, technical, economic and policy barriers. The study considered development of CSE as the broader purpose of the research and thus was not measured as a variable in the study.

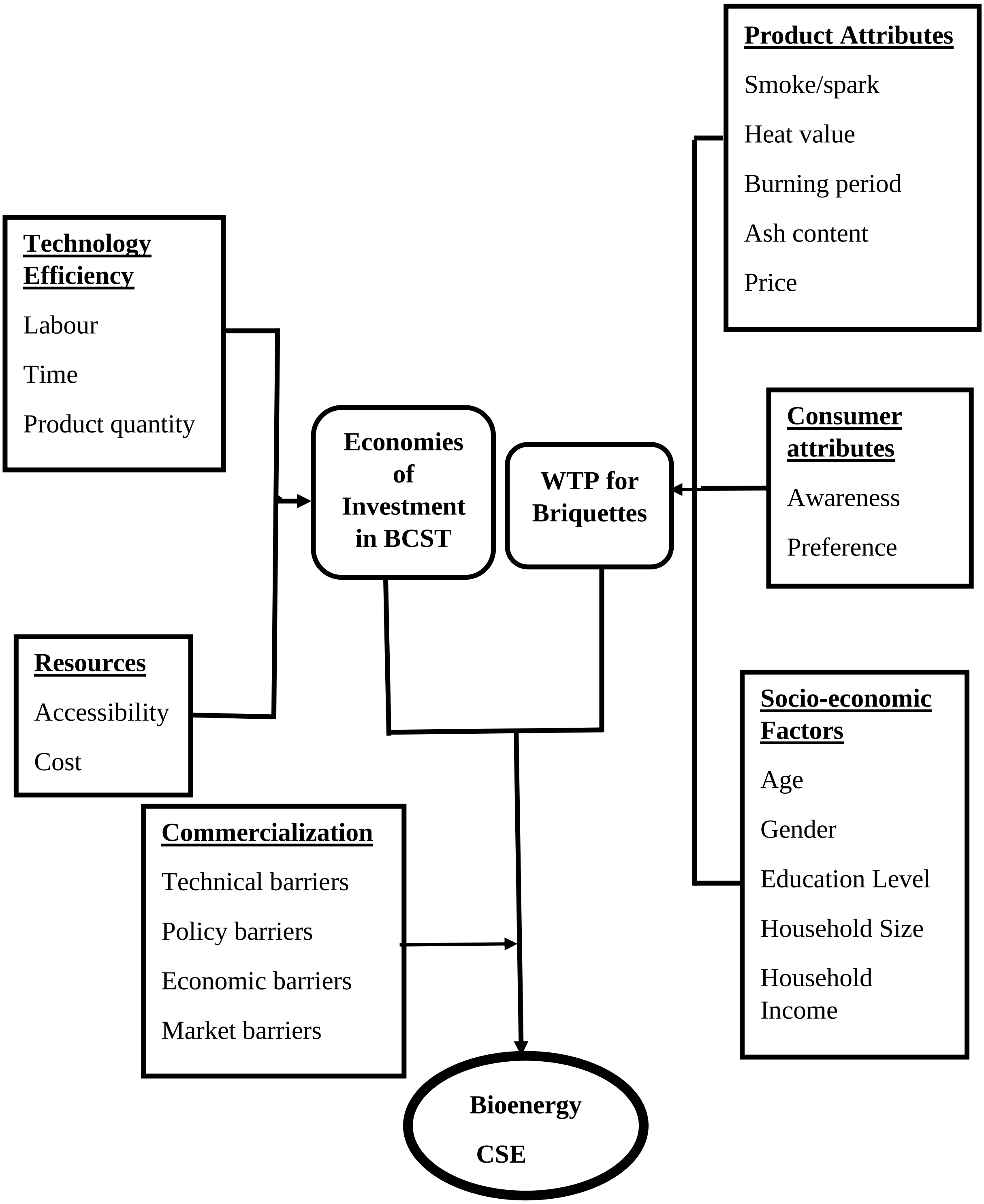

Figure 2.1. Conceptualization of the study

CHAPTER THREE

OBJECTIVE ONE

ECONOMICS OF BRIQUETTES AND CHARCOAL PRODUCTION TECHNOLOGIES IN KENYA: IMPLICATION FOR WIDE-SCALE COMMERCIALIZATION

Abstract

The purpose of this study was to evaluate the economic viability of investing in briquetting and charcoaling technologies among small-medium entrepreneurs. Specifically, the study estimated the cost of briquette and charcoal production using improved production technologies and determined the feasibility of the projects using specific economic indicators. Corncobs were used as the major agricultural waste raw material in briquette production whereas *Prosopis juliflora* (*Mathenge*) tree was used as feedstock for charcoal production. Economic analysis was done using a cost-benefit analysis method where the costs and revenues involved in briquettes and charcoal production were estimated. The cost of production is comprised of fixed, operations and maintenance costs estimated from the current market prices and based on different assumptions. Economic analysis revealed that unit costs of briquette production using drum agglomerator and screw press technologies were KES. 10.6 and KES. 17.83 per kg respectively, while production costs for charcoal were KES. 27.79 and KES. 35.60 per kg when using vertical and horizontal drum kilns at a proposed selling price of KES. 40 and KES. 50 per kg respectively. The study recorded positive net present values for briquette and charcoal production using all the four technologies. The highest net present value was recorded from drum agglomerator and vertical drum kiln technologies for briquettes and charcoal production respectively. Overall, production of briquettes and charcoal using the improved technologies was economically viable from the study results. The study gives a new direction to energy policy which could spur more interest among entrepreneurs willing to invest in the bioenergy sector.

3.1. Introduction

There is an urgent need to develop innovative technologies and energy sources that would help replace and reduce the use of fossil fuels thereby reducing greenhouse gases emissions (Bosire *et al.*, 2023). This is because of the rising global concerns for the environment brought about by climate change and the need for economic development and sustainability. However, the development of these technologies must be viable economically and environmentally to ensure sustainability. In this perspective therefore, the question lies on whether the new technologies are able to overcome economic challenges especially those affecting small-medium entrepreneurs. In this regard, bioenergy is gaining awareness and has contributed substantively to meeting the rapidly growing demand for energy globally (Kundu *et al*., 2018) with the largest number of dependencies coming from the developing countries (Bosire *et al*., 2023).

Baringo is one of the counties in Kenya with numerous charcoal entrepreneurs. There is need to develop technologies that would ensure charcoal is produced sustainably ensuring good health and environmental protection (Hamid & Blanchard, 2018). Biomass briquettes production is also an effective way to achieve clean and sustainable energy which in turn would enhance the promotion of clean and sustainable cooking enhancing the realization of SDG 7 on clean and affordable energy (UNDP, 2015).

The dedication of universities to commercialize their research is driven by the institution's own mission, values, and budgetary planning. By increasing their involvement in the expansion of the science and innovation sectors of the economy, universities want to speed up the commercialization of groundbreaking innovations and for socioeconomic development. To this end, Egerton University developed improved charcoal and briquette making technologies which were disseminated to various producer groups in Baringo county. These include screw press and drum agglomerator for briquette making and vertical and horizontal drum kilns for charcoal production presented in Appendix F. Through Kenya Climate Smart Agriculture Project Bioenergy Value Chain Project in Baringo, the university anticipated to contribute to mitigation of effects of climate change through the use of improved charcoal and briquettes making technologies, shifting the community from the conventional charcoal and briquettes production techniques. Despite the introduction of the technologies, there is limited information on the economics of these technologies for charcoal and briquettes production. This study therefore sought to analyze the economic viability of briquette and charcoal production of a small-medium entrepreneur using these technologies. The objectives of the study were i) to estimate the cost of briquettes and charcoal production using improved briquetting and charcoaling technologies and ii) to determine the feasibility of the projects using specific economic indicators. The study hypothesized that production of briquettes and charcoal using the improved technologies is profitable and economically viable.

There are a number of studies that have been done on economic feasibility of charcoal and briquettes production (Bourne *et al*., 2020; Chen *et al*., 2009; Chidumayo & Gumbo, 2013;

Chiteculo *et al*., 2018; Ekeh *et al.*, 2014; Kpalo *et al.*, 2020; Romallosa *et al*., 2017;). Most of these studies talk of production using traditional methods which have low production efficiencies unlike this study which is based on improved production methods. None of these studies focus on economic analysis of briquette and charcoal production in Baringo county using cost-benefit criterion. Hence, there is need for analysis of costs and benefits of improved production technologies with specific focus on Baringo which is one of the counties with the highest number of charcoal producers. The study provides the necessary knowledge required to improve the bioenergy sector's competitiveness in the country. It will enable entrepreneurs to make informed choices on investing in the industry. This study may also lead to increased adoption of improved charcoal and briquette making technologies which may result in improved sources of income, employment and process and product development in the bioenergy sector.

3.2 Methodology

3.2.1 Study Area

This study was carried out in Baringo county which is located in Northern Kenya in the Rift Valley region and is a major charcoal producing region in the country with most parts classified as arid and semi-arid. The county covers an area of 11,075.3 km^2 with a population of 666,766 and a population density of 60/km^2 (160/sq mi) (KEBS, 2019). It sited 250km west of Nairobi with an altitude of 1067m above sea level. It receives annual rainfall range of 1000mm – 1500mm in the highlands and 300-700mm in the lowlands per year with a mean monthly temperature of 32.8°C ± 1.6°C. Baringo borders Turkana and Samburu counties to the North, Laikipia to the East, Nakuru to the South, Elgeyo-Marakwet and West Pokot to the West.

Charcoal production is one of the main economic activities in Baringo with approximately 93.7% of the households engaged in its production (Ndegwa *et al*., 2021). 4 research sites were selected for the study including; GEWC Benoin Charcoal and Briquette Producers in Eldama Ravine, NIB Marigat group, Ilangua Group in Chemoigut and Loboi Charcoal Burners group in Loboi. Production sites were purposively selected from the producer groups' locations where charcoaling and briquetting machines had been disseminated by the KCSAP Bioenergy value-chain project from Egerton University. This project was a component of KCSAP that sought to support interventions that promote uptake of improved technologies in the bioenergy value chain. These technologies act as avenues to help reduce carbon gas emissions, thus promoting climate change mitigation agenda.

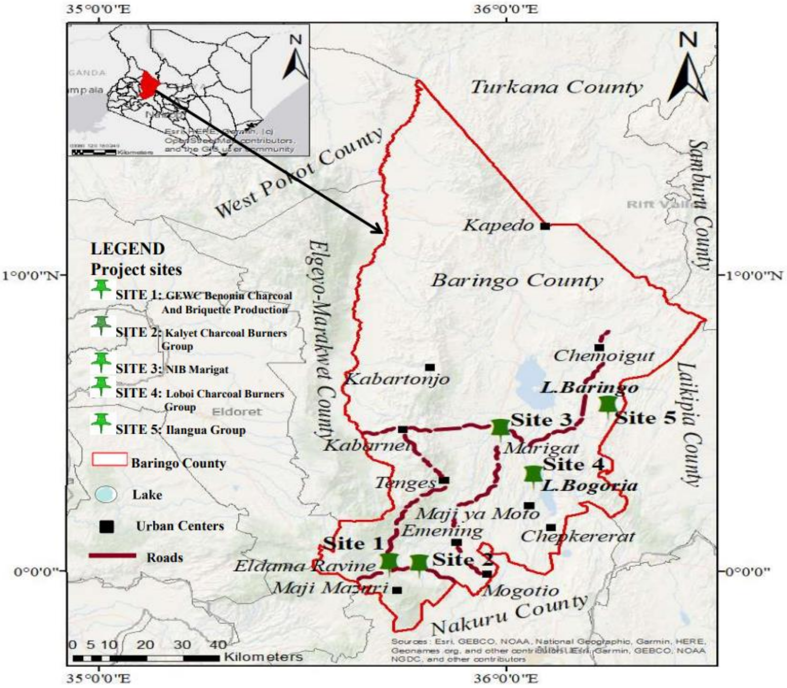

Figure 3.1. Map of Baringo county showing study sites

3.2.2 Data Collection

The study was an off-lab analysis by the end-users of the technologies (charcoal and briquette entrepreneurs). Corncobs were used as the major agricultural waste raw material in briquettes development and the quantities used noted. The raw materials were obtained from farmers' fields and NIB, Marigat for their availability in large quantities after maize harvesting. Briquettes development follows a systematic process as shown in Figure 3.2. The corncobs were dried to a moisture content of 8-12% (Ajimotokan *et al*., 2019). The dried corncobs were then carbonized in a drum kiln to obtain biochar that would then be crushed and densified to form briquettes. The time duration for the carbonization and densification was noted. To develop the briquettes using screw press, 5kg of biochar was weighed and molasses (used as the binder) sprinkled on it. This mixture was fed to the screw press for briquettes densification. For briquettes development using drum agglomerator, biochar was poured on to the drum and molasses sprinkled on top of the biochar as the drum rotated in the ratio of 6:1 for biochar to molasses. This was done until the briquettes granules grew to the desired sizes an approach that was used by Jamradloedluk and Wiriyaumpaiwont (2007). The formed spherical briquettes were then removed by hand and dried under shadow to avoid direct sunlight which would lead to briquettes cracking.

For charcoal production as shown in Figure 3.2, *Prosopis juliflora* (*Mathenge*) tree was used as the feedstock, a tree which has become invasive in the region. The tree species which not only has become invasive (Mbaabu *et al*., 2019), has also led to destruction of water sources as well as invading cropping land (Eschen *et al*., 2021). Controlled use of this tree is thought to be able to control its spread thus its suitability for use in the study. Only the branches of the *Mathenge* tree were used for research purposes to avoid cutting down the whole tree. As much as *Mathenge* is an invasive tree, it still acts as a good cover in the region being that the area is categorized as a semi-arid region. The wood was cut into small sizes about 50cm to fit the drum kilns. The drum kilns were fed with 55kg and 30kg of wood for vertical drum kiln and horizontal drum kiln respectively. The kilns' fireplaces were set, and the vents opened to allow in enough oxygen for carbonization for approximately 30 minutes. The fireplaces and vents were then closed for 2 ½ hours and 2 hours for vertical drum kiln and horizontal drum kiln respectively. After carbonization was complete, the vents were opened to allow offloading of charcoal.

Quantities of each input were noted and monetized to enable calculation of all the costs involved in production. Input parameters included labour, raw materials, machine and storage facility costs. The amount of labour was calculated based on the number of hours the labour was offered, which was valued at a fraction of the unskilled market wage. Quantities of output were also noted, and revenues earned calculated.

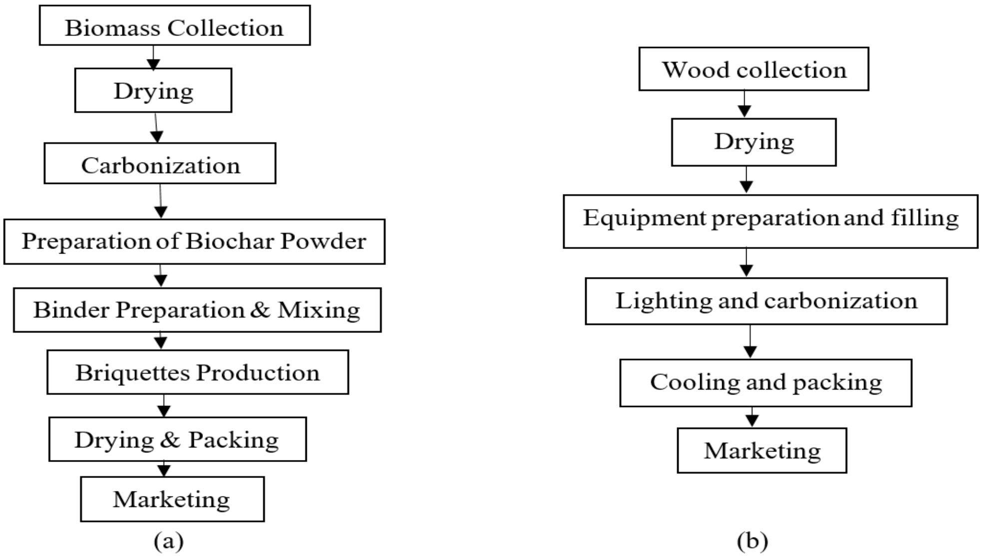

Figure 3.2: (a) Briquette production process and (b) Charcoal production process

3.2.3 Data Analysis and Calculations

Assumptions of the Study.

The capacity of the briquetting machine was 50 kg/h and 25kg/h for drum agglomerator and screw press respectively. This was derived based on the ratio of briquettes produced in kilograms to the average time taken in the production process by the briquetting machine. The machine capacity of the charcoaling technologies was 50kg/day and 90kg/day based on their sizes for vertical drum kiln and horizontal drum kiln respectively. Production time included the time the raw material was loaded into the machine, compaction/carbonization of the material for briquettes and charcoal respectively, briquette/charcoal residence and ejection from the machine. Being a new project to the entrepreneurs, the economic life of the technologies was assumed to be 5years.

The operation time of the technologies was assumed to be 8hours per day. The total number of operating days will be 240 days per year signifying 66% utilization capacity. A discount rate of 10% was assumed based on Pradhan *et al*. (2019). This is also in line with the global discount rate trend as mentioned by Kpalo *et al*. (2022) which lies closely to the CBK weighted average rates of 10.81% as at the time of the study. This is the current accepted rate used by most global approaches. A depreciation of 10% was assumed on the initial investment which was calculated using the straight-line method following Kaoma and Gheewala (2021) approach. The repair and maintenance cost of the machinery is generally assumed to range from 10-15% of the total cost of the machine operation and this normally increases as the useful life of the machine increases (Oluka & Nwani, 2013; Rotz, 1985). The study thus assumed a repair and maintenance cost of 10%. A price of KES.0.58/kg was assumed for the raw biomass material based on the projected cost of agricultural residues of USD 5/ton as found by Gujba *et al*. (2015). This cost was based on the annual growth rate of 0.1% from the US Energy Information Administration and may remain so until 2030 (EIA, 2021). The selling price of KES. 50 per kilogram was proposed for briquettes and Ksh. 2300 for 90kg/bag based on the current market prices.

Economic Feasibility Analysis

Feasibility indicators used in this study included net present value (NPV), internal rate of return (IRR) and payback period (PBP) as shown in Table 3.1.

Table 3.1. Economic indicators for the feasibility analysis

Economic indicator	Definition	Equation
Net Present Value	It denotes the present value of all future benefits minus the present value of cost required to invest.	$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} - I_0$……………………….(1)
Internal Rate of Return	The discounted rate that makes the net present value of the future net benefits equals the initial investment. It denotes the highest interest rate that would be paid by a project for all the resources that were used in the project if it wanted to recover its investment cost as well as the cost of operations and still make a profit.	$\sum_{t=1}^{n} \frac{R_t}{(1+i)^t} - I_0 = 0$……………………….(2)
Payback Period	The period it will take from inception of a project to recovery of the total investment cost.	

Source: Walekhwa *et al*. (2014). Where R_t is the Net cash flow at time *t*, i is the discount rate, *t* is time of the cash flow and I_0 is the initial investment.

The total production cost of briquettes and charcoal comprises fixed costs, operations costs and the cost of repair and maintenance. Fixed costs were the costs of the briquetting and charcoaling technologies fabrication, installation costs and the cost of the storage facility. Operation and maintenance costs include the cost of raw materials and processing including their transportation cost. Included in the operation and maintenance costs are the cost of labour, repair and maintenance. Machine cost accounts for the largest share of fixed costs for the briquetting and charcoaling technologies i.e. drum agglomerator and screw press (briquetting technologies) and vertical drum kiln and horizontal drum kiln (charcoaling technology). Raw material costs account for the largest share of the operation costs for all the technologies. The total revenue comprised of the total amount of briquettes and charcoal sold after a production period.

3.3 Results and Discussion

3.3.1. Cost of Charcoal Production

In Table 3.2, the total cost of charcoal production using vertical drum kiln is detailed. The total cost of production was also estimated from the capital expenditure and operations/maintenance expenditure. Machine cost (KES. 110,000) accounts for the largest share of fixed cost (representing 84.94%) while raw material cost (KES. 183,744) accounts for the largest share of operations and maintenance costs (representing 37.44%). A total of KES. 600,331.20 was the investment cost to produce 90kg bag of charcoal per day for 240days. Table 3.3. also presents the results for the production cost of charcoal using horizontal drum kiln. The drum has a capacity of producing 50kg of charcoal per day. For the drum kiln, the largest share of fixed cost was taken by the machine cost (KES. 30,000) whereas the cost of raw materials and processing accounted for the largest share of operation cost (KES. 231,360). A total of KES. 427,128 was the initial investment cost enough to produce 50kg bag of charcoal per day for 240days.

Table 3.2. Total cost of charcoal production for vertical drum kiln at utilization capacity of 90Kg/day

Item	Rate (KES)	Amount (KES)
(A) Fixed Cost (Initial Investment)		
A1. Machine cost	110,000	110,000
A2. Installation cost	1,500	1,500
A3. Storage facility cost	75/day×240days	18,000
Sub-total		129,500
(B) Operation Cost		
B1. Raw material cost	765.6/day×240days	183,744
B2. Raw material processing cost	500/day×240days	120,000
B3. Labour cost	500/day×240days	120,000
B4. Depreciation cost	10% of Initial Investment (A)	12,950
B5. Miscellaneous cost	5% Sum of (B1; B2; B3)	21,187.2
Sub-total		457,881.2
(C) Repair and Maintenance cost		
C1. Repair and maintenance cost	10% of Initial Investment (A)	12,950
Sub-total		12,950

Total Investment Cost	**600,331.2**

Table 3.3. Total Cost of Charcoal Production for Horizontal Drum Kiln at utilization capacity of 50Kg/day

Item	Rate (KES)	Amount (KES)
(A) Fixed Cost (Initial Investment)		
A1. Machine cost	30,000	30,000
A2. Installation cost	500	500
A3. Storage facility cost	75/day×240days	18,000
Sub-total		48,500
(B) Operation Cost		
B1. Raw material cost	464/day×240days	111,360
B2. Raw material processing cost	500/day×240days	120,000
B3. Labour cost	500/day×240days	120,000
B4. Depreciation cost	10% of Initial Investment (A)	4,850
B5. Miscellaneous cost	5% Sum of (B1; B2; B3)	17,568
Sub-total		373,778
(C) Repair and Maintenance cost		
C1. Repair and maintenance cost	10% of Initial Investment (A)	4,850
Sub-total		4,850
Total Investment Cost		**427,128**

3.3.2 Cost of Briquettes Production

The cost of producing briquettes comprised of fixed costs, operations and maintenance costs (variable costs) as detailed in Appendix G. The cost of the machine accounts for the largest share of fixed cost for both the drum agglomerator (KES. 150,000) representing 85.23% and screw press (KES. 100,000) representing 79.37%. The cost of raw materials (KES. 251,596.80) representing 18.01% and electricity cost (KES. 240,000) representing 32.88% accounts for the largest share of operations and maintenance costs for drum agglomerator and screw press respectively. The total cost of investment to produce 50kg/h and 25k/h of briquettes for a total of 240days was KES. 1,017,776.64 and KES. 855,928.32 using drum agglomerator and screw press respectively.

Briquettes production using the two machines requires a stable power supply for a maximum production efficiency. It is also to be noted from the results that raw materials account for a considerable share of the operation costs for both machines. For a successful briquette enterprise, the availability of raw materials should be considered a priority (Felfli *et al.*, 2011). The economics of any bioenergy enterprise is site-specific depending on the local conditions; thus, the enterprise requires close proximity to the source of raw materials. Baringo has abundant agricultural residues which are generated from agricultural activities especially from Pekerra Irrigation Scheme. These residues could potentially be utilized to produce sustainable bioenergy.

3.3.3 Cost of Producing a Unit of Charcoal/Briquette

The cost of producing a unit of briquette and charcoal and the annual revenue that could be generated from the sale of charcoal/briquette for the different technologies was also estimated as presented in Table 3.4. Given the machine capacities 50kg/h (drum agglomerator), 25kg/h (screw press), 90kg/day (vertical drum kiln), 50kg/day (horizontal drum kiln) and selling prices of KES. 50/kg for briquette and KES. 40/kg for charcoal, the total annual revenue can also be calculated. From the results, the proposed selling prices for a unit of briquette (KES. 50 per kg) and charcoal (KES.40 per kg) are both higher than the unit costs using different briquetting and charcoaling machines. This result is consistent with the results of Kpalo *et al*. (2022), where the unit cost for producing composite briquettes was USD 0.16 and the proposed selling price was USD 0.26 which was higher than the unit cost. This result however contrasts with the result of Kaoma and Gheewala (2021), whose unit cost of producing briquettes was higher than the proposed selling price. With the machines being operated for 240 days, 96000kg and 48000kg of briquettes will be produced for drum agglomerator and screw press respectively whereas, 240 bags (21600kg) and 12000kg of charcoal will be produced from vertical drum kiln and horizontal drum kiln respectively per year. Based on this, the annual revenue generated for the first year and subsequent years was estimated to be KES. 4,800,000, KES. 2,400,000, KES. 864,000 and KES. 480,000 for drum agglomerator, screw press, vertical drum kiln and horizontal drum kiln respectively.

Table 3.4: Cost of producing a unit of briquette and charcoal and annual revenue

	Drum agglomerator	**Screw press**	**Vertical drum Kiln**	**Horizontal drum kiln**
Total Investment cost (KES/year)	1,017,776.64	855,928.32	600,331.2	427,128
Unit Cost (KES/kg)	10.6	17.83	27.79	35.60
Annual revenue (KES/year)	4,800,000	2,400,000	864,000	480,000

3.3.4 Profitability Analysis of Briquette and Charcoal Production

Upon cessation of any business, the revenue obtained from the sale of all the business assets at that particular time is expected to be higher than the investment that was made (Vochazka *et al*., 2019). Thus, an economic analysis is important in determining the feasibility of any enterprise (Ifa *et al*., 2020). This section presents the cash inflow for each technology showing income and expenditure for a period of 5 years. The cash inflow data enabled calculation of the economic indicators for an entrepreneur engaging in briquette or charcoal production using these technologies. In Table 3.5, the NPV of briquetting project using drum agglomerator at capacity utilization of 66% and a discount of 10% was KES. 17,177,999.9. The positive NPV confirms financial profitability and investment viability in the briquetting project using drum agglomerator technology. Similarly, in Table 3.6, briquette production using screw press at a production capacity of 50kg/h would present a positive net present value indicating financial profitability and investment viability in the technology.

Table 3.5. NPV of briquette production using drum agglomerator

Time (Year)	**Cash inflows (KES)**	**$(1+i)^t$ (10%)**	**PV $=C/(1+I)^t$**
1	4,800,000	1.1	4,363,636.4
2	4,800,000	1.21	3,966,942.1
3	4,800,000	1.331	3,606,311.0
4	4,800,000	1.4641	3,278,464.6
5	4,800,000	1.61051	2,980,422.4
Total present value (TPV)			18,195,776.5
Initial investment (Io)			1,017,776.64
NPV			**17,177,999.90**

Table 3.6: NPV of briquette production using screw press

Time (Year)	Cash inflows (KES)	$(1+i)^t$ (10%)	PV $=C/(1+I)^t$
1	2,400,000	1.1	2,181,818.2
2	2,400,000	1.21	1,983,471.1
3	2,400,000	1.331	1,803,155.5
4	2,400,000	1.4641	1639232.3
5	2,400,000	1.60151	1,498,585.7
Total present value (TPV)			9,106,262.8
Initial investment (Io)			855,928.32
NPV			**8,250,334.50**

The capacity of the briquetting machines may have played a major role in determining the NPV of the technologies. Studies have indicated that plants with low capacity have had a negative NPV while those with large capacity had positive NPV. An example is a study done by Kaoma and Gheewala (2021), where negative NPV was reported for plants with lower capacities and a positive NPV for plants with higher capacities. This can also be noted in a study done by Hakizimana and Kim (2016), where a positive NPV of USD 17.2 million could justify its commercialization. Another related study by Sengar *et al*. (2013) noted a positive NPV of USD 25,831.88, USD 30,117.20 and USD 8434.78 for cashew shell, grass and rice husk briquette projects respectively. Other studies that noted a higher NPV include a study done by Feng *et al*. (2013) which recorded an NPV of USD 9.81 million and a study by Hu *et al*. (2014) recording an NPV of USD 1.40 million. The positive NPVs noted could then be interpreted as presenting the projects as feasible and economically viable.

In Tables 3.7 and 3.8, the results of the analysis of net present value for charcoal production using vertical and horizontal drum kilns are shown. Table 3.7. indicates that the projected earnings from investing in vertical drum kiln charcoaling technology discounted at 10% will exceed its projected costs at today's shillings, thus assuming a profitable investment. Table 8 similarly presents a positive NPV indicating a favourable return on investment using the horizontal drum kiln.

Table 3.7. NPV of charcoal production using vertical drum kiln of capacity, 90kg/day

Time (Year)	Cash inflows (KES)	(1+i)t (10%)	PV =C/(1+I)t
1	360,000	1.1	327,272.7273
2	360,000	1.21	297,520.6612
3	360,000	1.331	270,473.3283
4	360,000	1.4641	245,884.8439
5	360,000	1.60151	224,787.8565
Total present value (TPV)			1,365,939.417
Initial investment (Io)			600,331.20
NPV			**765,608.22**

Table 3.8. NPV of charcoal production using horizontal drum kiln

Time (Year)	Cash inflows (KES)	(1+i)t (10%)	PV=C/(1+I)t
1	192,000	1.1	174,545.4545
2	192,000	1.21	158,677.686
3	192,000	1.331	144,252.4418
4	192,000	1.4641	131,138.5834
5	192,000	1.60151	119,886.8568
Total present value (TPV)			728,501.0225
Initial investment (Io)			373,778.00
NPV			**354,723.02**

The Internal Rate of Return (IRR) for drum agglomerator, screw press, vertical drum kiln and horizontal drum kilns were 51%, 49%, 34% and 30% respectively as shown in Table 3.9. From the cash flows of the briquetting and charcoaling projects, the NPVs would be equal to zero at the aforementioned discount rates. A negative NPV will be obtained if the interest rate goes above the IRRs. This implies that the profits to be attained would be much less than the investment cost. An investment will be deemed profitable and economically viable if the value of IRR is greater than the allowed discount rate (Walekhwa *et al*., 2014). In related studies, Hu *et al*. (2014) obtained an IRR of 36% with a 4.4 years' payback period. When analyzing cost-benefit of charcoal briquette production, Onchieku (2018) noted IRR values of different setups; 68%, 76%, and 100% over a two-year production using a discount rate of 15%. These values were all greater than the discount rate value signifying profitable investments. The Payback Period (PBP) for drum agglomerator, screw press, vertical drum kiln and horizontal drum kiln was found to be 1year, 1year, 1.67years and 1.95years respectively. This implies that for all the projects, it will not take a lot of time to get returns on investment.

Table 3.9. Analyzing economic indicators of feasibility of briquetting and charcoaling projects

		Drum Agglomerator	**Screw press**	**Vertical Drum Kiln**	**Horizontal Drum Kiln**
S/No	**Indicator**	**Value**			
1	Net Present Value (KES)	17,177,999.90	8,250,334.50	765,608.22	354,723.02
2	Payback Period (Years)	1	1	1.67	1.95
3	Internal Rate of Return (%)	51	49	34	30

3.4 Conclusions and Recommendations

Economic feasibility analysis using cost-benefit criterion allows aggregation and comparison of positive and negative consequences of investments in monetary terms. These include the monetized costs involved in the investment and revenues gained. In this study, CBA was used as a decision tool to show feasibility of investing in improved briquetting and charcoaling technologies. From the study findings, it can be concluded that investing in improved bioenergy technologies is economically feasible and would be a good venture for small-medium enterprises who wish to expand their businesses taking consideration of the environment.

Developing technologies that are economically viable, especially for small-medium entrepreneurs, would attract more investors into the bioenergy value chain. This would also stimulate more innovations towards bioenergy sector which would help mitigate energy insecurity in Kenya. A new direction to energy policy can thus be proposed based on the positive economic analysis of the projects done. The government could invest more in the renewable energy sector to attract more attention from those who would wish to get into the bioenergy business. Its support could also be needed to put in place low interest rates to enable easier financial access to those entrepreneurs who would wish to borrow loans from financial institutions. Government could also facilitate the development of local bioenergy factories to spur more interest from local communities to invest in the sector. Innovators could continue to evolve briquetting and charcoaling technologies to make them as economical as possible. The study limited its scope to analyzing cost-effectiveness of four briquetting and charcoaling technologies, a comprehensive analysis could be proposed to compare the economics of these technologies and the conventional production technologies. Further research could also be done on the indirect benefits that could be obtained using these charcoal and briquette production technologies.

CHAPTER FOUR

OBJECTIVE TWO

WILLINGNESS TO PAY FOR BRIQUETTES AMONG RESIDENTS OF NAKURU COUNTY, KENYA

Abstract

The increasing energy demand brought about by population growth has necessitated the utilization of biomass briquettes as an alternative source of renewable energy. In an effort to contribute to energy security in the country, this study analyses the willingness to pay (WTP) for briquettes among urban households. The study builds on survey and discrete choice experiment data based on a sample of 384 households in Nakuru County, Kenya. Mixed logit regression results reveal that households highly preferred briquettes which produce less smoke with the highest marginal WTP for this attribute. This indicates that households are more cautious about the health implications than other attributes. The study also indicated that the availability of briquettes in Nakuru county was minimal and this calls for more campaigns that would encourage the use of briquettes as an alternative energy source. Biomass briquette enterprises also need to be recognized as important part of sustainable energy agenda and incorporated into policies such as those of bioenergy, environment and natural resource management

4.1 Introduction

The growing population and rising commercial industries have led to increased energy demand across the globe (Kpalo *et al*., 2020). Fossil fuels like petroleum, coal, natural gas among others dominate the global energy arena providing approximately 80% of the world's energy requirement (Sansaniwal *et al.,* 2017). Apart from depletion of these fossil fuels over the years, the energy industry has been presented by challenges of growing utilization which urgently calls for other sources of energy. Increased utilization of non-renewable fuels has positively contributed to the global economic growth but has also majorly contributed to increased carbon emissions which negatively impact on peoples' health and eventually contribute to global climate change (Tursi, 2019). Without appropriate mitigation measures, and with current trends in carbon emissions, it is projected that mean global temperatures might rise to 3.2^0C by 2100 (UNEP, 2019; Watts *et al*., 2018). Despite fossil fuels contributing majorly to global rise in temperatures, inefficient use of biomass fuel coupled with lack of appropriate household cooking technologies also contribute to this temperature rise. In most developing countries, biomass energy plays an important role as a major source of household energy. This represents about 3 billion people who primarily depend on biomass energy for household use (Anenberg *et al*., 2013).

Biomass energy constitutes approximately 14% of the global energy use and is a primary energy source for about three-quarter of people living in developing countries (Kumar & Singh, 2017; Baqir *et al*., 2018). It supplies 70% of national energy supply in Kenya (Mwakubo *et al*., 2018). Densification of biomass into briquettes could help reduce reliance on fossil fuels and also improve the utilization of biomass wastes. Briquette is a renewable energy source which can be effectively utilized for domestic heating and cooking. This will help increase the use of biomass energy which has been proven to be cost-effective and an effective way to reduce carbon gas emissions (Trubestkaya *et al*., 2019).

Biomass briquette is considered an environmentally friendly source of energy, and its adoption would help reduce greenhouse gases emissions and air pollution associated with other energy sources like coal, charcoal or any fossil fuel. Briquette is made from biomass waste, majorly including agricultural residues which are readily available in the country including sawdust, maize stalks, maize cobs, rice husks, coffee husks among others. These residues can easily be turned into briquettes thus providing a sustainable alternative energy and reducing reliance on forest wood as a major energy source (De Jong *et al*., 2017). Studies show that biomass briquette produces less smoke as compared to charcoal or firewood with a higher efficiency of 98% especially on energy saving stoves and 78% on ordinary cooking stoves. Charcoal and wood on the other hand have an efficiency ranging between 60-68% (Ali *et al*., 2019; Otieno & Awango, 2014; Sunar, 2022). It also burns with low ash content as noted by Mitchell *et al*. (2020). Furthermore, briquettes have been noted to burn with no odor and soot thus reducing the amount of household air pollution (Maneechot *et al*., 2020; Njenga & Karanja, 2014), and they burn longer as compared to wood and charcoal (Romallosa, 2017), which makes them an efficient source of energy to urban consumers.

The increasing population especially in these urban settlements comes with an increase in energy demand, that is mostly addressed by the use of wood-fuel and charcoal because they are considered economical, especially in the informal urban settlements. Use of clean energy generally depends on the household income, where higher levels of income are associated with the use of cleaner energy sources such as electricity or liquid petroleum gas (LPG) (Wu *et al*., 2012). As such, low-income groups may choose to use a certain fuel type based on the economic cost as opposed to comfort, convenience and environmentally friendly energy consumption. These preferences could be changed if households adopt the use of biomass briquettes as an alternative energy source. Moreover, biomass briquettes should easily fit into the supply chain currently serving charcoal and wood consumers in the urban settlements, hence providing an alternative energy source that simultaneously provides an environmental public good and promotes healthy cooking systems especially for women and children in urban households.

However, the public good nature of environmental co-benefits that are non-excludable implies that everyone would ultimately benefit in terms of a cleaner environment with less pollution and reduced emissions, so long as the majority adopt the use of briquettes. In addition, since the briquetting technologies require substantial capital investment, it is important to provide evidence about the potential demand. This forms the basis of this study and is a major motive behind analysing the willingness to pay for briquettes among Nakuru urban residents. The findings of this study will help formulate strategies to drive more initiatives that seek to promote cleaner and sustainable energy transitions. It will also help create penetration strategies for alternative energy and also improve campaigns on the importance of biomass energy for health and environmental sustainability.

4.2 Methodology

4.2.1 Study Area

The study was conducted in Nakuru country which lies about 1850 meters above sea levels on the highlands of Kenya. The county has a temperate climate year-round, although the temperatures may drop considerably in the cold season of June to August. The county's urban and rural population is 2,162,202 inhabitants according to 2019 census (KNBS, 2019). Agriculture, manufacturing and tourism are the backbones of the county's economy. The main crops grown include coffee, wheat, barley, potatoes, maize and beans. Dairy farming is also prominent in this region. Nakuru is the fourth largest city in Kenya, after Nairobi, Mombasa and Kisumu. Administratively, the county is comprised of 11 sub-counties/constituencies, and this study was carried out in one of the sub-counties (Nakuru Town West Constituency) as shown in figure 4.1.

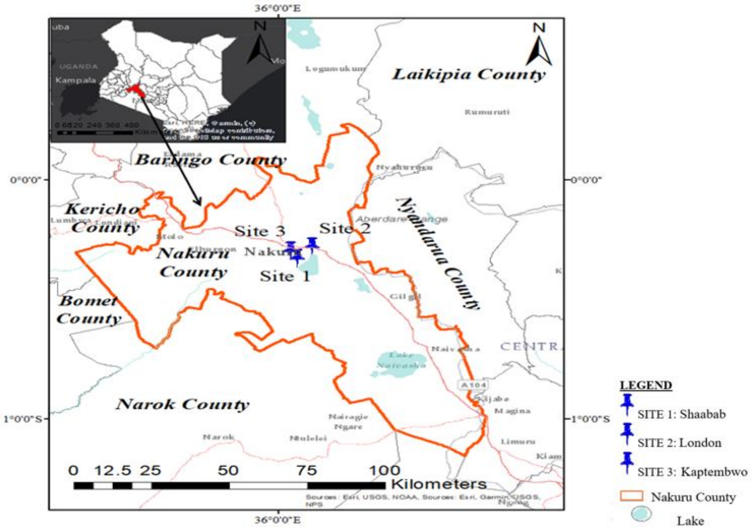

Figure 4.1. Map of Nakuru county showing study sites

4.2.2 Sample Size Determination

A total of 384 households from a target population of 64481 households (KNBS, 2019), was sampled from Nakuru Town West constituency. The sample size was calculated using Anderson *et al*. (2007) formula:

$$n = \frac{pqZ^2}{E^2} \quad \text{...}(3)$$

Where, n is the sample size, Z is the Z-score at 95% confidence level (Z = 1.96), p (0.5) is the maximum possible variance which was assumed to yield a sample size that would be statistically significant, q (1 - p = 0.5) is the weighting variable and E is the precision error (E=0.05). Thus, $n = \frac{0.5\times0.5\times1.96^2}{0.05^2} = 384\ households$

4.2.3 Sampling Procedure

A multi-stage sampling technique was used to get respondents (consumers) from Nakuru town. Within Nakuru Town West constituency, we purposively selected Shaabab, London and Kaptembwo wards. The aim was to include high- and low-income areas as part of the study sites. According to KNBS (2019), London ward is categorized as a high-income area while Kaptembwo and Shabaab are low-income areas thus were suitable for the study. A proportionate sampling strategy was then used to apportion the sample size to each ward (Table 4.1). Systematic sampling method was used to select respondent household within the ward based on lists provided by the ward officers. The sampling interval (k) was calculated using the formula:

$$k = {}^{N}\!/_{n} \quad \text{..}(4)$$

where, N is the total number of households in each ward and n is the target number of respondents in each ward (Table 4.1). Based on the alphabetically sorted lists, we selected the first household randomly and thereafter picked every k^{th} household systematically to achieve the target number of households per ward (n).

Table 4.1. Sample size distribution in the study area

Ward	Number of households	Proportion	Number of respondents
Kaptembwo	40,623	0.63	242
London	13,541	0.21	81
Shaabab	10,317	0.16	62
Total	**64,481**	**1**	**384**

4.2.4 Data Collection

The household survey was conducted in November 2022. Primary data was collected by use of personally administered structured questionnaires with the help of well-trained survey enumerators. Apart from the household survey questionnaire, the respondents were presented with DCE choice cards, both of which were pretested prior to the main survey. Pretesting was useful for validity and reliability testing. The pretest was carried out in Njoro sub-county where 38 questionnaires were administered which was approximately 10% of the required sample size of the study. The results of the pilot study were used to correct and adjust the final study questionnaires. After the main survey, the collected data was entered and processed in SPSS (statistics 21) then data analysis was done using STATA (version 15) software. Using SAS macros, choice sets were developed for the discrete choice experiment (Kunfeld, 2010).

4.2.5 Discrete Choice Experiment

Generating a consumer’s preference for a good can be done based on two approaches; revealed preference (RP) and stated preference (SP) approaches. The RP approach basically analyses a consumer’s preferences based on their real experiences with the products available in the market (TFR, 2023). The SP approach offers an advantage when there is a completely new product involved, that would not appear in the RP data collected based on choices in a real market (TFR, 2023). This study utilized the choice-based SP approach to elicit consumers’ preferences and willingness to pay for biomass briquettes. The approach involved presenting consumers with hypothetical briquette products and assessing how they value specific briquette attributes and trade-off between different attribute levels. This would not be possible to do with other common preference elicitation approaches such the Contingent valuation method (Adamowicz *et al*., 1998; Sibiko *et al*., 2018; TFR, 2023). Specifically, we used the discrete choice experiment (DCE) because of its consistency with economic theory. It is based on Lancaster's consumer choice theory, which assumes that consumers' preferences and decision judgement is a factor of the utility derived from the attributes of a good (Lancaster, 1966; Louviere *et al*., 2000).

4.2.6 Experimental Design

The process of designing the DCE started with a review of relevant literature to identify attributes of possible interest (Aina *et al*., 2009; Ajimotokan *et al*., 2019; Vivek *et al*., 2019). Then followed consultations with briquetting technology experts and producers. A pre-visit to the study area also allowed us to understand the context. Through this process we were able to narrow down the list of possible attributes to the ones that were most meaningful to consumers of charcoal and fuelwood in Kenya. We finally settled for five contract attributes as described in Table 4.2. The average number of attributes used in previous studies ranges from three to as high as eight (Bovenkerk *et al*., 2023). We believe that five was a good number of attributes so as not to overburden the participants while capturing as much as possible the required determinants of briquette demand.

Table 4.2. Attributes levels for choice experiment

Attribute	Description	Attribute Level
Price (KES/90kg bag)	Price for every 90kg bag of briquettes	2000, 2500, 3000
Smoke/spark	Whether briquettes produce less smoke and/or sparks during burning	Yes No
Heat Value	Amount of energy released as heat as briquette undergoes combustion	High (6000Kcal/kg) Low (4000Kcal/kg)
Burning Period	The period it takes the briquette to burn to ashes in a cook stove	Long (75minutes) Short (45minutes)
Ash Content	Amount of powdery residue remaining after the combustion of briquette	High (>6%) Low (<6%)

Among the attributes, the most obvious was the price attribute. This refers to the amount charged per 90-kilogram bag of biomass briquettes. Briquette price was set around the mean buying price of a bag of charcoal (KES. 2500) in the market. We included three levels for price

(KES. 2000, KES. 2500, KES. 3000) with an equal difference between them to make it easy to interpret the estimated coefficients. The price attribute is important to obtain marginal willingness to pay values for the other briquette attributes (Bovenkerk *et al*., 2023). The price was estimated based on the market prices at the time of the study, which was surveyed by the market sellers. “Smoke/spark” was described by two levels, that is, whether the briquette produces smoke or sparks when burning or not. Vivek *et al*. (2019) notes that biomass charcoal briquette burns with no smoke and does not produce sparks as compared to hardwood charcoal as a fuel for cooking. The level of smoke forming while cooking also reflects negative effects on the health and comfort in the consumer household (Bovenkerk *et al*., 2023).

The “heat value” or calorific value determines the energy content of a fuel. It is one of the most important fuel properties (Aina *et al*., 2009). Akowuah *et al*. (2012) reported that the calorific value of sawdust briquette was 4820Kcal/kg which compared well with the results obtained by Chaiklangmuang *et al*. (2008) of 4658Kcal/kg. Ajimotokan *et al*. (2019) also reported charcoal particles to have 5592.73Kcal/kg. We described heat value by two attribute levels: high (6000Kcal/kg) or low (4000Kcal/kg). The other attribute included is the “burning period”. This is the time taken by the briquette to burn to ashes in the cooking stove. Whereas the type of stove technology will also determine the burning time and efficiency in final use of briquettes, we expect that rational consumers would be willing to pay a premium for high-efficiency briquettes over ordinary charcoal. This attribute was described by two levels: short burning period (15-45minutes) and long burning period (45-75minutes).

The last briquette attribute included for the DCE design is “Ash content”. This attribute has not been included in the Malawi study by Bovenkerk *et al*. (2023), however, Mugabi and Kisakye (2021) noted that briquettes produce a lot of ash which was a challenge for users in Uganda. Briquettes with high ash content produce high combustion remnant that affect the heating effect of the briquettes. In other words, ash content is negatively related to the calorific value and both parameters measure combustion quality of briquettes (Kpalo *et al.,* 2020; Loo & Koppejan, 2008;). In their study, Ajimotokan *et al*. (2019) reported a briquette ash content range of 1.4%-6.0%. Ordinary charcoal is reported to have an ash content of 1-5% depending on the tree species used (Mugabi & Kisakye, 2021). To fit within this range, we described ash content with two levels: either low (<6.0%) or high (>6.0%).

Generation of Choice Cards

Choice cards were designed based on the attributes and attribute levels identified. Each card consisted of two options (option A and B) and the status quo option showing a consumer who did not choose any of the options. All possible attribute level combinations would result in a total of 48 (2^4x3^1) combinations. It would however be difficult for respondents to evaluate and compare such combinations. Using SAS macros, 8 generic choice sets were designed with a calculated D-efficiency of 0.72. These 8 sets were profiled into 2 blocks and each respondent assigned only one of these blocks randomly. Figure 4.2 shows a sample choice card for the choice experiment:

Briquette Attributes	**Option A**	**Option B**	**Neither A nor B**
Smoke/Spark	Yes	No	
Heat level	High (6000Kcal/kg)	Low (4000Kcal/kg)	
Burning period	Long (75minutes)	Short (45minutes)	
Ash content	High (>6%)	Low (<6%)	
Price (KES/50kg bag)	2000	2500	
Which briquette attribute option would you prefer?			

Figure 4.2. Sample choice card

Econometric Analysis

The study utilized Mixed Logit model for the econometric analysis of the DCE based on Random Utility theory (Louviere *et al.*, 2010). Mixed Logit model works on the assumption that the random part of the utility is distributed as IID (Independently and Identically Distributed) extreme value function. Therefore, the utility derived from adopting biomass briquettes can be decomposed into a deterministic and unobserved stochastic error compounds based on the product attributes preferred by the consumer. Based on the utility randomization theory, utility is considered a random variable which can be divided into different utilities based on the product's attributes. Therefore, the utility derived by consumer *i* from choosing alternative *j* from a choice card *k* will be given by:

$$\begin{aligned} U_{ijk} &= \alpha_i ASC + \beta_i X_{ijk} + \varepsilon_{ijk} \\ \beta_i &= \delta_i \beta + \gamma \eta_i + \delta_i \eta_i \end{aligned} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(5)$$

Where X_{ij} represents the vector of attributes and *ASC* is Alternative Specific Constant which captures those attributes that are not in the choice experiment, thus, takes care of no-response bias. The ASC is normally a dummy and is equal to 1 when the alternative is the opt-out alternative and 0 otherwise (WTP for briquettes). β_i=Vector of individual specific parameters, ε_{ijk}=idiosyncratic error, β= Vector of mean attribute utility weight, δ_i= Person-specific scale heterogeneity of the idiosyncratic error, η_i= Vector of individual specific deviation from the mean and γ= Scalar parameter governing variance of residual taste heterogeneity. This means that the value of utility of each consumer i was given by the sum of all the utilities from the attributes and the unknown error term ε_{ij} plus the constant α. Random Utility Theory leads to families of probabilistic discrete choice models that describe how choice probabilities respond to changes in choice options. Therefore, the probability that individual i choses option j from a choice set k was:

$$P_{ijk|l} = \frac{\exp(\beta_i X_{ijk})}{\sum_{j=1}^{ji} \exp(\beta_i X_{ijk})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

The values of Willingness to Pay for different varietal briquette attribute levels were given as:

$$\text{-}Marginal\ WTP = \frac{\beta attribute}{\beta price} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

The socio-economic characteristics of respondents were also determined, and the variables used in the analysis are as shown in Table 4.3.

Table 4.3. Socio-economic variables used in the analysis

Variable (X)	Description	Measurement
Socio-economic		
Age	Age of the household head	Continuous (Years)
Gender	Gender of the household head	Dummy (1=Male, 0=Female)
Education	Education level of household head	Ordinal (1=Primary, 2=Secondary certificate, 3=Tertiary education)
H/size	The size of the household	Discrete (Number of people in the household)
D/maker	Household decision maker	Nominal (1=HH, 2=Spouse, 3=Both)
Perception		

Awareness	Household’s awareness of briquettes	Dummy (1=Yes, 0=Otherwise)
Preference	Household’s bioenergy preference	Nominal (1=Woodfuel, 2=Charcoal 3=Liquefied Petroleum Gas (LPG), 4=Paraffin, 5=Electricity)

4.3 Results and Discussions

4.3.1 Characteristics of Respondents

Socio-economic characteristics of respondents: According to the study findings in Table 4.4, males headed the majority of households (65%), while females headed only 34%. The study sampled 384 respondents; however, some respondents opted out of the survey or did not complete the survey resulting in a total of 361 respondents used in the final analysis. In terms of age, the majority of household heads were between the ages of 40 and 49, accounting for 37% of the total sample size, with a mean age of 39 years. Education is important because it helps people learn new skills and informs many household decisions. The majority of household heads (45%) had completed secondary school, followed by those who had completed tertiary education (30%).

The type of energy source used by a specific household is determined by its income. The median household income ranged between KES 10,000 and KES 20,000. This implies that the majority of households will only use energy sources that are convenient for them based on their income level. Majority of respondents were involved in business activities, either as a businessman or a businesswoman (59.6%). This largely reflects the respondents' entrepreneurial nature, indicating that they are willing to engage in some activity that will generate income for them. Furthermore, as entrepreneurs, they are able to be risk takers and proactive in nature, which greatly contributes to their source of income and the improvement of their livelihoods. In the households that were interviewed, the household head was identified as the primary decision maker. This means that heads have a disproportionate influence over energy source decisions, which is attributed to them being the sole providers of income in their families, according to the findings on the household head. This is directly related to decisions and operations that are solely determined by household heads. The household size largely determines the type of energy source that will be used by the household. The mean household size of the respondents was 4 as indicated in Table 4.4.

Table 4.4. Socio-economics characteristics of respondents

Variables	**Description**	**Frequency**	**Response (%)**
Gender of the household head	Female	126	34.9
	Male	235	65.1
Age group	20-29 years	57	15.8
	30-39 years	117	32.4
	40-49 years	135	37.4
	50-59 years	40	11.1
	Above 60 years	12	3.3
Education level of household head	Nonformal education	3	.8
	Primary certificate	86	23.8
	Secondary certificate	163	45.2
	Tertiary education	109	30.2
Average income of household head	Below 10,000	88	24.4
	10,000 - 20,000	160	44.3
	20,000 - 40,000	84	23.3
	40,000 - 60,000	16	4.4
	60,000 - 80,000	8	2.2
Occupation	Businessman/lady	215	59.6
	Professionals	66	18.3
	Casuals	27	7.5
	Salespeople	18	5.0
	Riders/drivers	30	8.3
	Security officers/ police	5	1.4
Decision maker in the household	HH	204	56.5
	Spouse	13	3.6
	Both	144	39.9
Continuous variables	**Mean**	**Standard Deviation**	
Age of the household head in years	39.49	9.481	
Size of the household	4.18	1.578	

Preferred Energy Source. In six out of ten (62%) of the households polled, charcoal energy was the most preferred energy source, while paraffin was used by only 1% of the respondents. When asked why they chose specific energy sources as their preferred source, the majority (43%) stated that they preferred them because they are more cost effective than other energy sources. Other reasons for preferring a specific source included the fact that they saved time (20%) and were easily accessible/available (19%). According to Olang *et al.* (2018), the majority of households preferred a given type of energy due to its appliance type and cooking location, whereas in households experiencing high and low levels of energy poverty, access to the energy source and usage concerns respectively were reasons for their preferred energy source choice. Of the respondents, 61% stated that briquettes were rarely available in Nakuru Town, 34% said they were not available at all, and only 4% said they were able to find briquettes in Nakuru as indicated in Table 4.5. This could indicate the need to create more awareness of briquette so as to achieve more use among households.

Table 4.5: Preferred energy source among residents of Nakuru West Sub-County

Variables		**Frequency**	**Response (%)**
Most preferred source of energy	Wood fuel	17	4.7
	Charcoal	227	62.9
	Liquefied Petroleum Gas	114	31.6
	Paraffin	3	.8
Reasons for preferred energy source	Cost effective	157	43.5
	Accessible/ Available	72	19.9
	Health concerns	4	1.1
	Convenient	45	12.5
	Saves on time	74	20.5
	Provides warmth	7	1.9
	Produces no smoke	2	.6
Briquette availability in Nakuru Town	Accessible	5	4.8
	Rarely	64	61.0
	Not Accessible	36	34.3

Briquette Awareness and Perception: The study attempted to determine the briquette knowledge among those who had previously used briquettes and the perception of those who had only heard about briquettes and not used them before. Table 4.6 shows that there was little difference in briquette attributes between the two groups. Both groups were quizzed on the briquette trait they had encountered or perceived. According to 79% of users and 57% of non-users, briquettes are simple to store. Briquettes are simple to store because they can be stored in ambient conditions. In addition, unlike charcoal, they are easier to handle. Because of their compression during production, they are less dense and easier to store. These findings are consistent with those of Borah *et al.* (2019) and Elifadhili (2019), who found that the majority of households find briquettes easy to store due to their ability to be packed and handled easily.

Briquettes do not produce a lot of ash, according to 72% of respondents in both groups. This could be attributed to their composition materials, which produce less ash than charcoal. Kumar *et al.* (2021) documented similar findings by indicating that, when compared to pure charcoal, briquettes produce a low amount of ash due to an additional binder that helps reduce its ash content. Furthermore, according to Bonsu *et al.* (2020), ash content production is largely dependent on the content (inorganic and organic) used, resulting in its low ash content.

Briquettes also does not produce a lot of smoke, confirmed by 86% of users and 79% of non-user respondents. Previous research has shown that the majority of briquettes produce very little smoke, which is almost invisible (Widodo *et al.,* 2019), while others produce no smoke at all (Tesfaye *et al.,* 2022). This is entirely dependent on how the briquettes were prepared. Long-burning energy sources are preferred for cost savings. According to the study's findings, the majority of respondents (92%) and 84% of users and non-users, respectively, indicated that it burned longer than charcoal. These findings are consistent with those of Tesfaye *et al.* (2022) and Widodo *et al.* (2019), who found that briquettes have a longer burn time than charcoal.

Furthermore, the majority of users (85%) and non-users (75%), stated that the briquette energy source produced high temperatures. This is due to the fact that briquettes burn for a long time, increasing the likelihood of producing high temperatures. Another plausible explanation for this is the material used to make the briquettes. Nonetheless, this is beneficial to households because it is more durable due to the long burning periods that result in high temperatures. Nurek *et al.* (2019) discovered similar results, indicating that briquettes produce high temperatures as a result of material compaction, which increases durability. In cost comparisons of charcoal and briquettes, both users (64%) and non-users (55%) indicated that briquettes were more expensive than charcoal (Table 4.6), which is consistent with Akolgo *et al.* (2021) findings. This could be due to the fact that briquette use has still not gained publicity in the region and the few marketers available could be taking advantage of that gap and thus the high prices.

Table 4.6: Briquette awareness and perception among users and non-users

Briquette attributes		**Users (105) Response (%)**	**Non-users (256) Response (%)**
Briquette is easy to store	No	21.0	43.0
	Yes	79.0	57.0
Briquettes produce a lot of ash	No	72.4	72.7
	Yes	27.6	27.3
Briquettes produce a lot of smoke	No	86.7	79.3
	Yes	13.3	20.7
Briquettes have a long burning period	No	7.6	16.0
	Yes	92.4	84.0
Briquettes produce high heat temperatures	No	14.3	24.6
	Yes	85.7	75.4
Briquettes cost high compared to charcoal	No	35.2	44.5
	Yes	64.8	55.5

4.3.2 Households' Preferences for Briquettes

Table 4.7 shows households' preferences for biomass briquettes. The Log Likelihood was -656.059 while Chi^2 was 63.82 statistically significant at 1% level of significance. This indicates that all the variables entered in the econometric model were statistically sufficient for a good model fit. All variables that were entered in in the model were all positive except smoke/spark production. All the variables were significant at 1% level of significance, except for ash content which was significant at 10% level of significance. This also tells that the briquettes attributes and attribute levels used in the model were essential in determining households' preferences for briquettes as alternative source of energy. The standard deviations for smoke/spark production and long burning period were statistically significant at 1% level of significance while high heat level was significant at 5% level of significance. This indicates that there was presence of preference heterogeneity among the respondents who participated in the experiment. Thus, mixed logit model was a valid model to be used in the analysis of the objective.

Table 4.7: Households' preferences for briquettes

Variables	Coefficient	Standard error	p-Value
Price	0.000	0.000	0.009***
Smoke/Spark Production	-0.909	0.236	0.000***
High heat level (6000 Kcal/kg)	0.522	0.171	0.002***
Long burning period (75 minutes)	0.979	0.213	0.000***
High ash content (>6%)	0.239	0.145	0.100*
Derived standard deviations of parameter distributions			
Smoke/Spark Production	1.841	0.432	0.000***
High heat level (6000 Kcal/kg)	0.855	0.353	0.015**
Long burning period (75 minutes)	1.547	0.425	0.000***
High ash content (>6%)	0.107	0.658	0.871
Goodness of fit			
Log Likelihood	-656.059		
LR Chi2(4)	63.82***		
n(respondents)	361		
n(choices)	2166		

***, **, * = level of significance at 1%, 5% and 10% respectively.

The decision of whether or not to adopt briquettes as an alternative source of household energy depends on the characteristics of briquettes and the benefit a household would receive with regards to the adoption. The results of the study indicate that households preferred briquettes with long burning period which had a positive estimated coefficient and significant at 1% level of significance. The magnitude of the coefficient of long burning period was the highest (0.979) among all the briquette attributes. This shows that households most preferred briquettes with long burning period even though they also showed preference for other attributes like high heat level. Long burning periods offer households the luxury to cook meals that require long cooking hours without necessarily using a lot of fuel which would translate to high fuel expenditures. This result is also consistent with the results of Njenga *et al*. (2019), where they noted that urban residents prefer briquettes as a source of household energy because they burn for longer periods especially those made from a mixture of charcoal dust and soil.

High heat level was the second most preferred attribute after the long burning period with an estimated positive coefficient of 0.522 and 1% level of significance. Households preferred to have briquettes with high heat value which would cook faster to reduce the amount of time being spent cooking. Heat value is one of the most important fuel properties and differs depending on the type of biomass used as raw materials in making briquettes (Aina *et al*., 2009). This result is in line with that of Akowuah *et al*. (2012), where 76% of respondents agreed that briquettes produce high heat content with a longer burning period especially when compared to charcoal. From the study, it was also noted that 93% of the respondents were willing to use briquettes if they were made available, stating that it was more efficient.

High ash content had a lower preference with an estimated coefficient of 0.239 at 10% level of significance. Households preferred to have a cooking fuel that produces less ash as they were cautious about the discomfort that comes with higher ash producing energy fuels. Fuel with higher ash content usually leads to high dust emissions which might cause allergies, pollution and inefficiency in the fuel burning (Katimbo *et al*., 2014). Ash content has been noted to cause combustion remnants which lead to inefficient heating effects (Sotannde *et al*., 2010). Studies, however, have noted that ash content in briquettes is subject to the type of raw material used in its production. Some studies indicate that briquettes have low ash content whereas other studies note a higher ash content depending on the type of raw material that was used during production. For instance, studies by Okowuah *et al*. (2012) and Adetogun *et al*. (2014), both reported a lower ash content of 2.6% and 1.06% respectively. These studies however contradict the studies done by Emerhi (2011), Ogbuaga *et al*. (2013) and Ige *et al*. (2018), who noted higher ash contents of 19.07%-21.72%, 10.44%-42.33% and 18% respectively. These differing results would be explained by the composition of the different raw materials that were used during briquettes production. A biomass cooking fuel is said to be of high quality when it has an approximate ash content of 4-6% (Falemara *et al*., 2018).

Smoke/spark production attribute had a negative coefficient of -0.909 at 1% level of significance. Households prefer cooking energy with less smoke because of health and environmental concerns associate with smoke (Bovenkerk *et al*., 2023; Person *et al*., 2012). Briquettes have been noted to burn with less smoke (Vivek *et al*., 2019) and would therefore be a good choice for household cooking energy compared to charcoal and wood. Households would therefore not be comfortable with any cooking fuel that is associated with excessive smoke production for their health and environmental concerns.

4.3.3 Sources of Preference Heterogeneity

The presence of preference heterogeneity as shown in Table 4.8 indicates that there was variation in the preferences for briquettes attributes across different household respondents with similar observed characteristics. Preference heterogeneity was shown by interactions between random parameters and household characteristics which was estimated by the use of mixed logit model, a procedure noted by Pambo *et al*. (2014). Interactions followed an iterative process of model estimation which was compared using simulated log likelihood procedure. The results in Table 4.8 show significant interactions with a good model fit. The interactions included; HHGen_BurnLong representing the interaction between the gender of the household head (HHGen) and Long Burning period (BurnLong) attribute, HHAge_SmokeYes the code for the interaction between the age of the household head (HHAge) and production of smoke/spark (SmokeYes) attribute, HHAge_BurnLong the code age of the household (HHAge) and long burning period (BurnLong) attribute and IncHH_BurnLong the code for the interaction between the income of the household head and Long Burning period attribute.

The first part of Table 4.8 indicates the mean estimates of the preferred briquette attributes as discussed in Table 4.7, the second part shows the interactions between the random parameters and household characteristics, the third part shows the standard deviations of parameter estimates while the last part indicates the goodness fit of the model. If the results of tables 4.7 and 4.8 are compared there is a notable improvement in the goodness fit of the model from log likelihood of -656.059 to -647.562. This shows that, including the interactions improves the goodness fit of the model.

Table 4.8: Possible sources of preference heterogeneity

Variables	Coefficient	Standard error	p-Value
Smoke/Spark Production	-2.495	0.790	0.002***
High heat level (6000 Kcal/kg)	0.522	0.171	0.002***
Long burning period (75 minutes)	0.857	0.739	0.246
High ash content (>6%)	0.233	0.145	0.109
Price	0.000	0.000	0.009***
Interactions			
HHGen_BurnLong	0.669	0.341	0.050**

HHAge_SmokeNo	0.042	0.018	0.021**
HHAge_BurnLong	-0.028	0.017	0.098*
IncHH_BurnLong	0.361	0.160	0.024**
Derived standard deviations of parameter distributions			
Smoke/Spark Production	1.727	0.442	0.000***
High heat level (6000 Kcal/kg)	0.876	0.353	0.013**
Long burning period (75 minutes)	1.558	0.430	0.000***
High ash content (>6%)	0.126	0.718	0.861
Goodness of fit			
Log Likelihood	-647.462		
LR Chi2 (4)	59.26***		
n (respondents)	361		
n (choices)	2166		

***, **, * =level of significance at 1%, 5% and 10% respectively.

The interaction between gender and briquette long burning period denoted by HHGen_BurnLong had a positive and significant coefficient at 5% level of significance. This means that preference of briquettes with long burning period would increase by 66.9% among male headed households. This could be explained by males always wanting value for their money. A long burning briquette means that the briquette will be able to cook for a long time before converting to ash. As a result, one would have cooked so much before having to refill the stove. The long burning briquette will therefore mean that the amount of fuel used for cooking would be low and thus a reduced fuel cost. The time advantage makes briquettes suitable for preparing foods that require a longer time to cook such as dry grains, which would otherwise be abandoned by household due to high fuel consumption that increases the household fuel costs (Njenga *et al*., 2013).

The interaction between age and smoke level denoted by HHAge_SmokeNo had a positive and significant coefficient at 5% significance level. Preference for briquette with no smoke would increase by 4.2% as age increases. Due to health and environmental risks associated with smoke, households would prefer those energy sources that produce less smoke. Smoke has been associated with negative health effects like respiratory and eyesight related health problems, heart illnesses and cancer (Diette *et al*., 2012; Person *et al*., 2012). Older people were more conscious about the effects of smoke on their health and preferred briquette that produces less smoke. This support can be justified by mutual acknowledgement of the adverse impact of pollutants on health (Tainio *et al*. 2021) as well as the negative effects of pollution experienced by the respondents.

The interaction between age and long burning period attribute denoted by HHAge_BurnLong had a negative and significant coefficient at 10% significance level. Age reduced the preference for briquette attribute with long burning period by 2.8%. Older household heads shifted their preference from long burning briquettes. This can be explained by the fact that older household heads are usually more endowed in terms of resources than younger household heads and therefore can afford to acquire fast cooking energy sources making long burning period a less preferred attribute. Simtowe *et al.* (2016) argued that older households are less constrained in terms of finances.

The interaction between household income and long burning period attribute had a positive and significant coefficient at 5% level of significance denoted by IncHH_BurnLong. The increased need of low-income households to live within tight financial budgets is accomplished through the use of energy fuels that are able to cook for long before burning into ashes, as opposed to consuming fuels that would burn to ashes faster before cooking is complete. Longer burning period would thus be more preferred by high income household since they are not constrained by the high cost of fuel that comes with fuels burning for a short period of time.

This study revealed that gender, age and household income were significant sources of preference heterogeneity for preferred briquette attributes including long burning period and smoke production. However, the derived standard deviation for the smoke attribute was still significant at 1% implying that heterogeneity in preference for the attribute was caused by other factors other than the socio-economic factors included in the model.

4.3.4 Willingness to Pay for Briquettes Attributes

This sub-section presents results for the estimation of Willing to Pay (WTP) for biomass briquette attributes. The price attribute represented the purchasing price for briquettes and was captured as price per 90kg bag. The results in Table 4.9 present the WTP estimates in monetary value (KES) that respondents place on the various briquette attributes, as determined by the coefficient estimates. The price coefficient enabled estimation of Marginal Rate of Substitution (MRS) between briquette attributes and money interpreted as marginal willingness to pay for a change in each attribute. The effect of each attribute was not predetermined and therefore, the willingness to pay values could take any sign.

The results also show the rate at which respondents are willing to trade off one briquette attribute for another using marginal values. It is presumed that respondents in overall, were willing to pay the for long burning period attribute (KES 4901.388/90kg bag of briquette) followed by Smoke/Spark Production attribute (KES 4553.018/90kg bag of briquettes). This indicated their willingness to pay for an energy source that does not cause indoor air pollution while also satisfying their luxury to cook for a longer time period. The least preferred attribute was high ash content (>6%) (KES 1195.26/90kg bag of briquette). This could be associated with negative effects associated with the dust particles produced which could cause respiratory irritations and also affect the combustion system of the fuel, thus reducing cooking efficiency (Kpalo *et al.*, 2020; Loo & Koppejan, 2008;).

Table 4.9: Estimated Willingness to pay for briquette attributes

Variables		Marginal WTP	95% Conf. Interval
Smoke/Spark Production		-4553.018***	-154.5374 to -8951.498
High heat level (6000 Kcal/kg)		2614.629***	5849.724 to 620.4662
Long burning period (75 minutes)		4901.388***	9827.836 to 25.0606
High ash content (>6%)		1195.255*	3150.818 to 760.3071
n (respondents)	361		
n (choices)		2166	

***, * =level of significance at 1%, and 10% respectively.

The willingness to pay estimates highlighted the extent to which a household values the briquette attributes. A first observation is that WTP values for briquette attributes average around the same value for smoke production and long burning. This means that households were willing to pay more for no smoke and long burning period attributes despite the price mark up. This is justified by the fact that the attainment of a clean and sustainable energy sources is at the core of achieving Sustainable Development Goal 7 (UNEP, 2019) which encourages universal access to clean energy and improvement in energy efficiency as a priority for sustainable development. It should however be noted that this analysis was based on stated preference data which is subject to hypothetical bias. Thus, WTP values should be interpreted as high preferences rather than a strategy to develop feasible price mark-up for briquettes (Gamboa *et al.*, 2018).

4.4 Conclusions and Recommendations

Several studies have indicated that biomass briquette has the potential to reduce overreliance on charcoal and woodfuel, consequently reducing carbon gas emissions and the pressure on forests. The results of our study indicate that a good percentage of respondents had knowledge about briquette but had not used it before. This could be attributed to the inaccessibility of briquettes in the city. Briquette use has not spread across Nakuru county and this calls for a strong campaign to promote briquette use so as to facilitate transition to green energy sources with low costs to consumers. From the experience of briquette users, it was evident that briquettes can safely be used as an alternative to charcoal which is prominent among the residents of Nakuru county. Households' respondents had a strong preference for briquettes with long burning period and less smoke production as the most important traits as indicated by the high value of willingness to pay. Preference heterogeneity varies by socio-economic characteristics.

To increase biomass briquette, use as a mitigation strategy to climate change, knowledge and accessibility of briquette should be increased. This could be achieved by organizing trainings to educate households on briquette making technologies. Briquette making groups could be established in Nakuru as a means to mentor households on briquette making, not only for household consumption but also for income generation for improved livelihoods. Biomass briquette enterprises also need to be recognized as an important part of sustainable energy agenda and incorporated into policies such as those of bioenergy, environment and natural resource management.

CHAPTER FIVE

OBJECTIVE THREE

DETERMINING THE PATHWAYS FOR COMMERCIALIZATION OF BIOENERGY TECHNOLOGIES AND PRODUCTS AMONG STAKEHOLDERS IN THE BIOENERGY VALUE CHAIN

Abstract

Bioenergy has emerged as a suitable alternative to fossil fuels with a potential to significantly contribute to the country's energy targets. The implementation and development of bioenergy provides other secondary benefits which could be utilized for the wellbeing of vulnerable communities. However, the well-established fossil fuel industry presents a challenge to finding a suitable pathway to commercially develop the bioenergy industry. Other factors such as government policies, financial constraints, lack of stakeholders' coordination, technical complexities and market chain barriers also contribute to the stagnation of the sector. This paper sought to analyse these barriers, opportunities existing to overcome them and proposes a pathway to commercialize bio-technologies. The research placed stakeholders of the bioenergy value chain at the centre of the analysis, thus complementing the existing literature, giving it a user-cantered approach. Data was collected through a series of semi-structured interviews and interactive focus-group discussions allowing stakeholders to share their experiences and perspectives. The analysis of the barriers to bioenergy expansion helped identify opportunities that would improve the design and policy implementation, financial constraints and technological difficulties. The findings of this study are not only relevant for the development of transition strategies to low-carbon energy futures in Kenya but also other developing countries that are struggling with energy transitions.

5.1. Introduction

Bioenergy is regarded as the next major source of renewable energy alternative to fossil fuels. It is a major driving force to climate change mitigation which will ensure sustainability of the energy industry (Chan, 2018). Studies have noted that the development of sustainable energy sources and mitigation of climate change effects depend largely on the development of the bioenergy sector at a commercial scale (Parra *et al.,* 2023; Smith & Porter, 2018). The bioenergy sector has the capacity to supply approximately 15% of the world's energy demand come 2050 (Fischer & Schrattenholzer, 2001; Parra *et al*., 2023).

The bioenergy industry is a vital component that will enable transition from fossil fuels (Morone & Yilan, 2020) and contribute to the achievement of a circular economy (Fiallos-

Cardenas *et al*., 2022; Manzanares, 2020). The increasing population and the rising energy demand has resulted in numerous environmental and health concerns. This has also been linked to the growing food insecurity globally. The utilization and use of biomass energy is therefore seen as an effective means to greenhouse gases emissions (Namany *et al.,* 2019). Studies have also indicated that commercial deployment of bioenergy sources could help reduce the global temperatures below the pre-industrial levels (Bauer *et al*., 2020; Jouvet & Perthuis, 2013), thus helping to achieve a sustainable future.

Commercialization of bioenergy technologies is a direct contribution to the achievement of affordable, clean and sustainable energy (Sustainable Development Goal, SDG7), climate action agenda, SDG 13, the realization of sustainable cities and communities, SGD11 and attainment of responsible consumption and production, SDG12. It is a safeguard against environmental depletion (IEA, 2021) and a means of introducing energy efficient technologies to minimize carbon gases emissions (Jonsson & Martin, 2016). Despite the urgent need for biomass energy and the positive prospects of the bioenergy industry, commercialization of bioenergy technologies and biofuel products is still faced with several hurdles. These challenges have been presented in different forms including sustainability of production capacity of the technologies (Avila-Arozca *et al*., 2020), production costs (Woinaroschy, 2014), among others. This study seeks to highlight the current status of bioenergy industry, existing challenges towards a sustainable industry and possible solutions to these emerging gaps in the commercialization quest.

Several studies have attributed the staggering uptake and use of biofuels to the minimal efforts put towards commercialization (Usmani *et al*., 2021). A study conducted by Javed *et al*. (2021) states that a sustainable commercialization effort of biofuel products depends majorly on the economic sustainability of the enterprise. Emphasis is also made in studies such as Nieto *et al*. (2021), Frattini *et al*. (2011) as well as Eldred and McGrath (1997). Other studies also state factors such as the legal framework conditions and the low returns that may be realized after investing so much in making the machinery attractive (Kemausuor *et al*., 2015). All these studies stress the importance of a good commercialization strategy especially on a new product development and sustainability of a given value chain. Uptake of a new product in a given market is primarily dependent on the product’s commercial aspect which will eventually determine its market penetration and development or failure (McKinsey, 2010).

The concept of commercialization has been given different perspectives by different researchers. Some researchers suggest that commercialization involves a sequence of scientific work that aids in a new product development and movement from a laboratory into a new market (Shakeel, 2017). Other studies view commercialization as a process of getting the views of the product's consumers which is based on the product's performance and reliability. The objective is to ensure that the satisfaction of a customer can be sustained throughout the life of the business (Balachandra *et al.*, 2010). Some researchers view it as a process of using a product's uniqueness and transforming it into a sustainably profitable enterprise (Adams *et al.*, 2006), while others state that it is the last phase of the development of a product closely linked to its launch and marketing (O'Connor, 2008).

It is evident that, as much as commercialization has been studied, it is still a growing concept. It is also to be noted that the penetration of bioenergy technologies into the market does not stop at laboratory success but largely dependent on successful commercialization. Bioenergy has the potential to enable transition into a sustainable energy industry through the use of sustainable technologies. However, this potential transition will remain on paper or inside the laboratories unless there is a large-scale diffusion of these technologies. This paper is curious to investigate the possible barrier to the development and commercialization of bioenergy technologies and possible opportunities existing that could be tapped to fill the gaps in Kenya.

By looking at the challenges hindering commercialization potential of the bioenergy value chain, this study complements the work of Balan (2014), Balachandra *et al*. (2010), Chandel *et al*. (2018) and Frattini and Chiesa (2011). The study offers an opportunity to rethink the existing policies that would help push the bioenergy sector to sustainability.

5.2. Methodology

5.2.1 Description of the study area and data collection

The study was conducted in Baringo county in Northern Kenya. This county was selected as part of the KCSAP Bio-energy value chain project site. The county was also selected as one of the main charcoal production regions in the country, making it necessary to introduce bioenergy technologies in the region. The project sought to promote climate smart biotechnologies which would help reduce the use of forest wood and lessen the amount of carbon emissions while improving the bioenergy value chain. Five (5) sites were purposively selected i.e. GEWC Benoin Charcoal and Briquette Producers in Eldama Ravine, Kalyet Charcoal Burners Group in Mogotio, NIB Marigat group, Ilangua Group in Chemoigut and

Loboi Charcoal Burners group. These are the charcoal and briquette producer groups directly involved in KCSAP.

The primary research approach placed key stakeholders of the bioenergy value chain at the centre of analysis. This complemented the existing literature on bioenergy giving it a user-cantered approach where key stakeholders are given a chance to voice out their experiences. Two sets of stakeholder consultations were carried out engaging representatives from sectors such as policy, business, civil society and academia. Informed consent was obtained by all participants and the stakeholders. The first consultation was focusing group discussion with 75 charcoal and briquette entrepreneurs, 15 from each of the 5 producer groups, randomly selected. Participants discussed the benefits of improved bioenergy technologies, barriers to commercialization of the technologies and opportunities existing for wide-scale development of bioenergy enterprises. The second consultation included 5 semi-structure interviews carried out among a variety of stakeholders from different backgrounds like the research, environment and industry (fabricators of bioenergy technologies, Kenya Forest Research Institute, Ministry of Environment and Forestry, Kenya Forest Service, Ministry of Water, Sanitation and Irrigation). The interview included questions to identify the existing policies and strategies that support bioenergy, willingness to uptake and expectations from the community with regards to the technology, barriers and opportunities for bioenergy technology development and commercialization.

5.3. Results and Discussion

This section represents the results for the determination of the pathway for commercialization of bioenergy technologies and products. The results showed; the major barriers to commercialization process and possible solutions, a SWOT analysis of the bioenergy value chain and proposes a pathway for bioenergy commercialization. Literature presents various drivers that promote uptake of bioenergy technologies and products including a) sustainable and renewable energy supply, b) an inclusive economic growth to reduce overdependence on fossil fuels, c) establishment of a circular economy and contributing to building a green environment (Oh *et al*., 2018; Valdivia *et al*., 2016).

However, several challenges were identified that affect commercialization efforts of bioenergy technologies and products, including; imbalanced demand and supply of biofuels, unsteady supply of biomass used as feedstock in the production processes, lack of information flow from programmes promoters and target adopters, high capital investment and operation costs, technology complexity and not meeting the needs of the adopters, insufficient public policies on biofuels, lower returns on investment and inability of the technologies to be reproduced. All these challenges were generally categorized into four themes, i.e. a) market environment barriers and opportunities, b) technical barriers and opportunities, c) economic barriers and opportunities and d) policy barriers and opportunities as presented in figure 5.1.

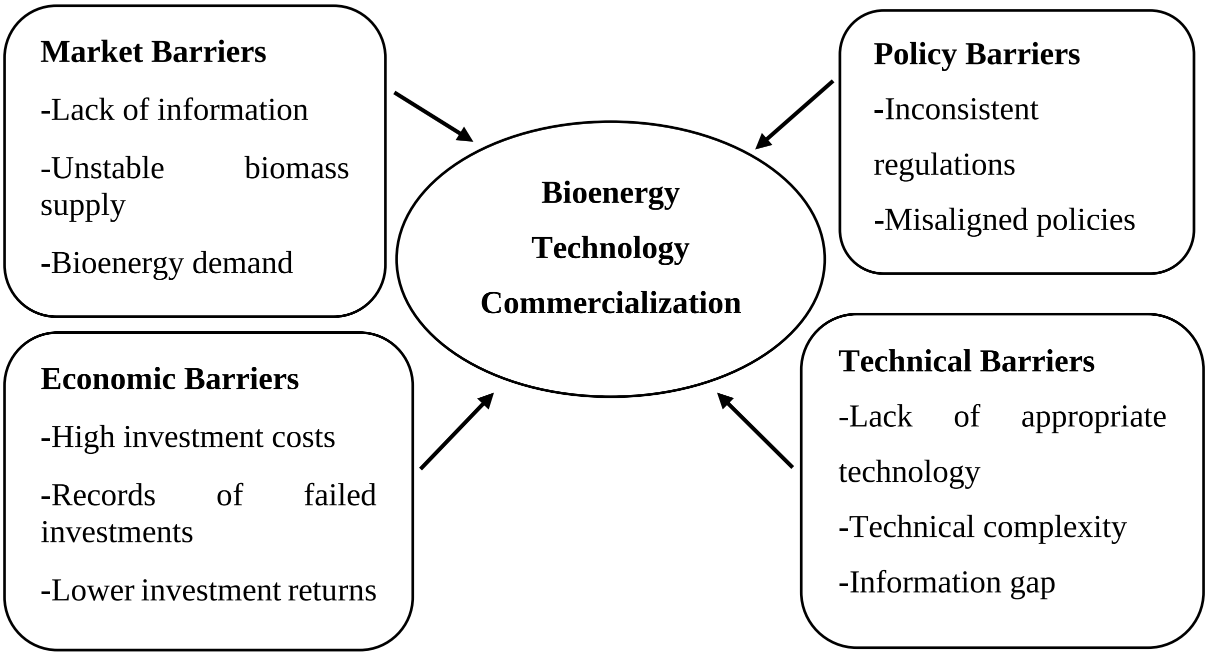

Figure 5.1: Major barriers affecting commercialization of bioenergy technologies

5.3.1. Market Barriers and Opportunities

A number of challenges were noted surrounding the market environment of bioenergy technologies and products. These included; lack of information among stakeholders, unsteady supply of biomass, challenges with demand of biomass energy. These are discussed in the sub-sections below:

Lack of Information among Stakeholders: Difficulties in operating most of the technologies were attributed to lack of streamlined information between the programs promoting the technologies and the adopters of the technologies. Many entrepreneurs reported that they were neither properly informed on the benefits nor trained on the functioning of most of the technologies. The literature points out lack of clear information as one major barrier to full commercialization of bioenergy technological information (Mwirigi *et al*., 2009). Information on the use of the technology should be very clear to enable adopters to appreciate its benefits. Other stakeholders felt that the introduction of such initiatives in the communities did not fully take into account the opinions of the locals and identify their needs or interests before deployment. This could be the cause of poor adoption of such technologies as the locals could feel their opinions are not incorporated and thus failed full commercialization attempts.

Other stakeholders noted a lack of consistent monitoring of the projects' success after deployment. Several projects, especially government supported, only conduct monitoring on the technology performance during the first few months of the project after which they stop monitoring to ascertain the success of such projects to the communities they are deployed to. They conduct patchy performance evaluations which do not encourage the adopters of the technologies. This leaves the users of the technologies trying to find solutions, especially to technical problems which they may not understand well enough to solve. As a result, they end up abandoning the technology and continue with their conventional production methods. One stakeholder argued that sometimes the technologies may not even work properly in the field during demonstrations which would instil doubt among the adopters. They may question the viability of such technologies and investment feasibility. Any doubt in operational feasibility of a technology to a user may prevent any investment attempt which would lead to such projects diminishing at the trial stage.

Stakeholders therefore suggested a transparent and reliable information flow between the promoters and the adopters of the technologies to create investment interest. Some solutions suggested by stakeholders included community trainings and capacity building which might make the locals have interest in investing in the technologies. The government could also lead campaigns as a way of creating awareness among the communities. An entrepreneur argued that adopters of the technologies in the community can create greater influence on other members and cause wider adoption of the technology. This is particularly manifest in communities where there is communal sharing of resources like Baringo, e.g. sharing of the irrigation water from Pekerra river at the Pekerra irrigation scheme. This communal sharing creates a sense of togetherness thus the adopters have an easier lead in convincing others.

Unstable Supply of Biomass: A year-round supply of biomass material is a critical issue when starting a bioenergy enterprise. Stakeholders reported that there is need for an agreement to be put in place between supply of the biomass material (agricultural crop residues, wood among others) and biofuel producers. The cost of managing and transporting the feedstock from the farms to the production sites/factories is a cost that must be taken into account before engaging in biofuel production. This is because these costs affect the overall economics of the enterprise.

The literature notes that, for large scale production of biofuel, approximately 40-60% of the production cost is taken up by logistics, transportation, production of feedstock and feedstock processing costs (Humbird *et al*., 2011). The aim of any enterprise is usually to reduce the cost of production and realize good returns on their investments. For cost competitiveness, the production site should be located in close proximity with the biomass material production farm so as to reduce the associated with logistics and transportation. Production cost will increase if the enterprise is located far from the biomass farm due to increased transport cost (Balan, 2014).

Most entrepreneurs do not take into consideration these issues especially when looking at the operational feasibility of their bioenergy enterprises. Transport cost was found to be a major factor of consideration for it cuts across all stages of production from processing of feedstock, storage and transport from the harvesting farm to the factory/production site. Entrepreneurs should also understand the type of feedstock that would ensure economic gain since different feedstock have different bulk densities. For instance, grass crops have bulk density of 50-100kg dry matter m^{-3} lower than corn with a density of 721kg dry matter m^{-3} (Chandel *et al*., 2018), which would in turn affect the efficiency of feedstock supply. Therefore, before engaging in a bioenergy production enterprise, it is important to ensure that the biomass supply chain is able to meet the economic aspects of the enterprise. This would empower farmers, entrepreneurs and the larger population to adopt such technologies.

Demand for Biomass Energy: Demand and supply are major aspects to be considered in the uptake of bioenergy technologies and biofuels. Before releasing a technology/product into the market, it is important to study and ascertain the demand for that technology or product. If a technology is not able to meet the demand of the target market, then competitors including the current technologies being talked down by the industry would service the demand. Stakeholders argued that, for a technology to break into the market efficiently, it needs to create more interest to the community than the existing and adapted technologies.

To create more interest, a stakeholder suggested that projects could identify better ways to exploit the markets by ensuring multiple benefits from using the technologies. For instance, for the case of biomass carbonization technologies, apart from getting the major output i.e. biochar, the technology is also able to produce wood vinegar, the liquid obtained when smoke is condensed during pyrolysis of wood (Zuraida & Budijanto, 2011), which has multiple uses in pest and disease control in farm crops. The liquid has been found to contain antifungal, antioxidant and insecticidal properties (Faisal *et al*., 2019) which could be used to boost crop production. Wood vinegar can be used in various forms including fertilizer, plant growth hormone as well as wood preservative (Salim *et al*., 2021; Yahayu *et al*., 2017). This promotes a cyclic environment where the vinegar is used in the production of the feedstock which would eventually be used as a raw material in the carbonization process. Strengthening the market for these secondary products could be a promising opportunity for the commercialization of the technologies. These secondary products could also have a greater savings potential on the expenses of the adopters e.g. reducing expenses for purchase of chemical pesticides. Therefore, a technology that presents multiple benefits would attract more adopters who would then increase the scale of such technologies.

5.3.2. Policy Barriers and Opportunities

Several policies have been put in place by the Kenyan government to promote modern bioenergy services in which planning, and development of energy regulation has been devolved by the Kenyan Constitution 2010. Biomass fuel has been recognized as a vital source of energy in the country by The National Energy Policy 2018 stating that wood fuel management is vital in order to meet the growing energy demand. The National Climate Change Action Plan (NCCAP) 2018-2022 also identifies key actions that need to be taken to ensure increased adoption of renewable energy in order to achieve a low-carbon economy. The implementation framework for energy, that includes bioenergy, has been set forth by The Energy Act, 2019 which provides regulations for licensing and management of all renewable energy sources.

With all these policies and regulations put in place however, stakeholders stated that bioenergy companies are subject to multiple fees, licenses as well as taxes especially when the company is formally registered. The regulations were also noted that they were not consistent across both formal and informal sectors. This makes the informal sectors more market competitive than the formal sector since the competition is not on a level ground. The Forest (Charcoal) Rules of 2012 gazetted in 2009 and revised in 2012, specifically regulates sustainable production, transportation and marketing of charcoal which the Kenyan Constitution 2010 mandates the county government to foresee. Entrepreneurs stated that it was difficult to get licensed for charcoal production especially as an individual since the constitution demands licensing be done to groups (Charcoal Producer Associations (CPA)) through Kenya Forest Service (KFS) and no retailer or wholesaler is allowed to do business with unlicensed group.

At the national level, it was noted that there was misalignment of policies. This is because there are both policies governing renewable and even the coal power plants which threaten the bioenergy industry. The government may be more concerned with fuelling development rather than reducing the amount of carbon emission as argued by a stakeholder. At the community level, in some cases, financial support may be given for running of the deployed technologies to a candidate who does not really care about the success or failure of the project. Based on the criteria used by the program, for instance a candidate’s past experience, the person selected might not be the best suit for the position thus resulting in project failure.

As a solution course, stakeholders argued that there could be improvement in the renewable energy policy framework. There could be more biofuel targets to motivate the private sector to invest more in bioenergy programmes. A stakeholder suggested that the devolution of the government could be taken as a strength to develop the bioenergy sector. The county governments have significant policy making and budgetary powers. The government could use its powers to source funds and channel them to development of the bioenergy sector in their regions. The county government could therefore go beyond the national policies to invest in bioenergy projects towards the development of its region.

5.3.3. Technical Barriers and Opportunities

Technical complexity of bioenergy technologies is a major drawback in successful commercialization of these technologies. Research efforts in laboratories may not always be workable in the actual field where the technology is deployed (Chandel *et al*., 2018). There still exists a major gap between laboratory research and field operations, especially at commercial levels since parameters estimated in the laboratories may not always be applicable or viable when the technology is deployed at commercial levels. An entrepreneur argued that sometimes technology may require a lot of technological improvements in order to be fit for a commercial operation. These improvements may come with huge costs which may not be met easily by the entrepreneurs. The handling of the technology may require expertise and experience posing a challenge to entrepreneurs who might have the interest to invest but lack the expertise to operate the technology. Some entrepreneurs might not welcome the idea of incurring training costs before engaging in operations.

Processing biomass in order to get the right feedstock may be tedious. For instance, in the case of briquetting technologies, the raw biomass has to be processed (carbonized under low oxygen concentration) before getting the biochar as the major raw material for briquette making. This often increases the production cost and the complexity of the production process in cases where the briquettes entrepreneur has to produce the biochar himself. A stakeholder argued that these new, technologically immature technologies can be difficult to operate since most of the faults that could have been made in the laboratories have not been removed to ensure smooth running of the machine. Thus, such technologies require that they are operated for some time to correct any technical problem that may arise before deploying them for commercial use. In order to obtain the desired product therefore, all the steps of operations especially for the automated machines should be followed as a prerequisite of the success of the bioenergy enterprise.

5.3.4. Economic Barriers and Opportunities

The study noted several barriers in the business environment that would hinder commercialization of bioenergy technologies. One major barrier was the established fossil fuel industry which has greatly spread among communities. State owned corporations like National Oil Corporation of Kenya (NOCK), dominate the industry dictating prices which the small and upcoming bioenergy companies would barely compete with. Another barrier noted by the stakeholders was the lack of after-sale services such as maintenance and warranties. Bioenergy companies or institutions promoting bioenergy technologies rarely offer maintenance after the technology is deployed to the entrepreneur. This therefore forces the entrepreneurs to hire sub-standard services from uncertified technicians which consequently increases the maintenance costs. This affects the viability of such projects with regards to commercialization.

Other barriers included lack of financial support which significantly affects the implementation and development of bioenergy enterprise (Nevzorova & Kutcherov, 2019). Where an entrepreneur cannot afford the financial implications that comes with implementation of bioenergy project, such project would not reach the commercialization stage (Aha & Ayietey, 2017; Kitheka *et al.*, 2019). Cost deliberations are crucial in commercial activities and stakeholders argued that investors will only find a business attractive when they can afford its establishment and gain return on investment. High capital and operation costs were found to have major influence on commercialization of a bio-enterprise. Cost is an important factor to be considered in determining the overall interest in investing in any technology (Bößner *et al.*, 2019). The cost of investing in bioenergy technology varies depending on the season when and region where the investment will take place. The feedstock costs, especially for briquettes production, varies with season and this affects the investment cost i.e. the cost of agricultural crop residues like corncobs or even forest wastes. The cost of obtaining the feedstock, storage and transportation also increases the overall investment cost (Chandel *et al.*, 2010).

Entrepreneurs will therefore invest in the business when he or she is sure of the profitability of the business.

Stakeholders suggested that entrepreneurs could come together to co-fund their investments since the investment cost of bioenergy technology could be way above the reach of a small-scale entrepreneur. This would not just create revenues to the investors but also build a sense of ownership where the investors see the enterprise as a future investment which could result in a long-term commercialization plan. Co-financing has been seen to improve longevity of technology investment rather than individual financing which would be very expensive for ordinary producer (Buysman & Mol, 2013). Technology providers could also provide repair and maintenance services to the entrepreneurs in order to reduce such costs which could also come with warranties. This would greatly encourage investment in such technologies as opposed to when the entrepreneur/investor has to take care of all the costs of the technologies especially in the early stages of investment. The institutions could also invest in training communities on the operations of the technologies and training some of them as technicians, which could create more job opportunities especially for the youths of the communities involved.

5.3.5. SWOT (Strengths, Weaknesses, Opportunities and Threats) Analysis of a Bioenergy Enterprise

SWOT analysis of a bioenergy enterprise focused on four major parameters i.e. strength and weakness which affect the enterprise from within and opportunities and threats affecting the enterprise externally. These parameters were analysed on a business and strategic viewpoint and are presented in Table 5.1 below. Several strengths and weaknesses have been noted when looking at the pathway to commercialize a bioenergy enterprise. The need to reduce carbon gas emissions in light of the changing climate, increasing demand for energy, promoting economy and creating employment is growing across the world. This growth, however, is seriously affected by high capital investment in the technology, high operation cost, technical complexity which do not see such projects proceed to commercialization points (Chandel & Silveira, 2017). The bioenergy industry has also offered several opportunities which if utilized can just be the breakthrough to the commercialization of the technologies since climate change actions are at the top the world’s sustainable development goals agenda (SDG 13-Climate action).

Regardless of the opportunities that exist, there are those factors that threaten the development of this sector. For instance, recent failures in attempted investments in the industry still threaten any potential investor who might have interest in getting into the industry. Policies that promote fossil fuel production also threaten the industry as investors are swayed by the profitability of such investments. In order to change this situation, more policies should be put in place to encourage public/private partnerships that could help move the industry (Valdivia *et al.*, 2016). Researchers could also put on more efforts in coming up with ways in which industrial challenges could be addressed and how every stakeholder could be included to benefit the industry (Dale, 2018). With reference to the strong points, the bioenergy industry could be able to improve the rural livelihoods by promoting enterprise development and employment opportunities. The government could therefore support the industry by encouraging public/private partnerships and correcting unfavourable tax regimes.

Table 5.1. SWOT analysis of a bioenergy enterprise

Strengths (Internal)	**Weaknesses (Internal)**
• Supply of clean energy and reduced carbon emission. There is an urgent need for technologies that would increase climate change resilience. There is thus an increase in advocacy for sustainable solutions to climate change • Sustainable energy source utilizing renewable resources such as agricultural waste, forest residues • Bioenergy production often uses locally available raw materials, reducing dependency on imported fuels and supporting local economies. • Job creation enhancing economic development • Ability to create an environment for continuous technological improvement • Contribution to scientific knowledge	• Technology complexity especially for commercial levels • High capital and operation costs • Knowledge gap between laboratory and field/factory operations • Land use conflicts- land use for food production vs land use for technology feedstock production • It is difficult to get capital to invest in demonstrations before deploying the technology • Minimum stakeholder engagement • Difficulties in navigating complex regulatory landscapes, including permits and compliance with environmental standards, which can be time-consuming and costly.
Opportunities (External)	**Threats (External)**
• There are advocacies in place for reduced carbon emission	

• Climate smart agriculture agenda at the forefront • Opportunities for job creation and employment • Opportunities for scientific knowledge creation • Increased awareness on bioenergy technological innovations • Increased push to exploit the countries natural resources	• Records of failed investments in the industry which discourage potential investors • High capital and operation costs for demo plants and commercial operations • Policy issues that continue to boost non-renewable energy • Constant change in technological innovation processes • Unreliable response from potential investors • Inconsistent climate patterns that threaten biomass production and likewise the prices of feedstock

From the challenges and the opportunities existing in the bioenergy industry as noted from key informant interviews and the literature reviewed, commercialization pathways were thus proposed as below:

- Establish public-private partnerships in the bioenergy sector. Partnerships could be at any level; local (user) level where local entrepreneurs partner with each other, fabricator level and institutional level which include researchers and policy makers. Partnerships at the local level are especially good when entrepreneurs want to share the investment costs. It allows a sense of ownership of the enterprise such that every party involved in the partnership would work towards ensuring the success of the enterprise. The government could establish national bioenergy policies and strategies that would help push the development of commercial bio-industries. Collaboration of all the stakeholders (industry, small-medium entrepreneurs, academia and NGOs) is especially important in ensuring a synchronized benefit is achieved in the sector. The government could partner with the local innovators in the bioenergy and create incentives for the growth of the sector. Partnering with other sectors like the biomass production sector would also be important in providing raw materials for the enterprises. Fabricators could ensure that the technologies are simpler to use and would require minimal costs of repair and maintenance to attract more investment. An effective feedback mechanism could also be designed between user of the technologies and fabricators to ensure information flow regarding the suitability and viability of the technologies to the users. This would help in improvement on the designs of the technologies to make them more user friendly. Research institutions could partner with industries to ensure a collaborative effort is put to disseminate the technologies to the targeted users effectively.

- Simplify the designs of bioenergy technologies. One challenge that would limit commercialization of technologies is a complex design that would not be applicable at entrepreneur level. Such complexities come with huge capital costs of construction as well as operations. Investors require easy to handle technologies that would not see them increasing their capital expenditure and thus reducing the revenue earnings. While targeting local entrepreneurs, the designs should be made in a manner easily understandable to the entrepreneurs for them to appreciate its value. That would spur interest from other entrepreneurs who would then create a chain of investment promoting the spread of the technology to the wider population.
- Investing in Research and Development (R&D). Research and development allow for a continuous improvement of the technological designs by researchers or innovators. This allows an opportunity to realize faults that may exist on prototypes and mend them before deploying technologies to the outside population which could accelerate the development of the industry. Technological improvements allow technologies to be user friendly and more replicable among adopters. Therefore, government, investors and other stakeholders could channel more funds towards research and development for the improvement of the sector.

5.4. Conclusions and Policy Recommendations

Overall, the results of the study reveal that bioenergy is a promising industry which could replace fossil fuels and facilitate economic growth, infrastructural development, and social wellbeing of communities if properly utilized. The bioenergy industry could offer a great relief in energy supply across the country even though a number of barriers still exist that hinder its full utilization, for example, lack of properly targeted policies, technical and financial constraints. However, the positive impacts of bioenergy could continue to be enjoyed if certain considerations are put in place. For instance, the technologies could be made simpler to suit a common user i.e. the operational complexities of the technologies could be reduced to be more friendly to the small-medium entrepreneurs who wish to invest in the industry. Designing these technologies to better utilize the secondary benefits that come with their implementation to generate additional income could be a way to ensure sustainability. These co-benefits also increase investment interest in cases of slow return on investment.

Stakeholders from all the relevant sectors like policy, environment and market chains are therefore called upon to collaborate to effectively develop an industry that is sustainable. Research institutions could help with identifying the technological complexities that may hinder adoption and rectify them before dissemination. Relevant policies and strategies could also be put in place in order to ensure that the bioenergy industry is competitive in the world energy mix.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1. General Discussions

The need to attain a low-carbon future is at the centre of climate action agenda giving the energy industry a new or renewed growth trajectory. The growing pressure on fossil fuel which is increasingly diminishing and with a very high utilization rate has led to climate change. To mitigate climate change and halt future energy crises, there is an urgent need for alternative sources of energy. Bioenergy presents an opportunity to replace fossil fuels and stakeholders are coming up with different ways to improve the sector, trying to create pathways for a sustainable energy industry. Several technologies are being made and disseminated among entrepreneurs to help produce bioenergy in an economically and environmentally sustainable manner and improve livelihoods. However, the development of bioenergy industry is still lagging. Charcoal, which dominates the sector, still continue to be produced traditionally causing increased environmental impact and compromising peoples' health through excessive smoke released. Briquette technology is also gaining momentum but at a sluggish rate. Industries are coming up with technologies that they believe would help improve the sector, but these technologies rarely develop to commercial stage. The industry is gaining momentum, and the government needs to put policies that would help ensure the industry is sustainable.

The development of improved charcoal and briquettes production technologies by Egerton University was a move towards contributing to climate change mitigation. From the analysis of the economics of these technologies, it is noted that charcoal and briquettes production using the improved technologies would be economically viable as noted from the positive net present values and short payback periods. The development of briquette markets would also be an effective way to provide alternative cooking fuels to households which would help reduce indoors carbon emissions and consequently contribute to reduced greenhouse gases and health implications. However, as technologies are being developed, their uptake still remain low. This may be caused by the investment capital required or lack of knowledge among the entrepreneurs and consumers intended. This sluggish embrace of bioenergy technologies could also be caused by complexities of the technologies especially for entrepreneurs who would wish to venture into the industry but lack the technical skills to operate such technologies. This calls for innovators to be more simplistic with their innovations to make them more user friendly so as to attract entrepreneurs. It is also imperative that strong campaigns be put in place that would help ensure that the knowledge about bioenergy technologies is spread among the bigger population.

6.2. Implications of the Study

6.2.1. Economics of investment in briquetting and charcoaling technologies in Baringo

The study's results underscore the economic promise of using improved charcoal and briquette production technologies developed by Egerton University, demonstrating their substantial potential for investment and commercialization in the bioenergy sector. By evaluating these technologies through key economic indicators; net present value (NPV), internal rate of return (IRR), and payback period, the study reveals that both charcoal and briquette production can deliver favourable financial returns.

Specifically, the vertical drum kiln for charcoal production achieved an NPV of KES 765,608.22, indicating a robust return on investment, while the horizontal drum kiln yielded a lower, yet still positive, NPV of KES 354,723.02. The higher NPV associated with the vertical drum kiln suggests it offers greater profitability compared to the horizontal drum kiln. In comparison, the briquette production technologies show even more impressive results. The drum agglomerator's NPV of KES 17,177,999.90 and the screw press's NPV of KES 8,250,334.50 highlight their superior economic performance. These outcomes align with similar studies, such as Ifa *et al*. (2020), which found positive NPVs for bio-briquettes, thereby validating the study’s results and reinforcing the economic viability of these technologies. The study also resonates with those of Kpalo *et al*. (2022) and Hakizimana and Kim (2016), who both in their studies for economic analysis of briquette production found positive net present values.

The implications of these findings are significant for stakeholders in the bioenergy sector. The short payback periods observed; 1.67 years and 1.95 years for the vertical and horizontal drum kilns, respectively, and just one year for both briquette production technologies-suggest that entrepreneurs can expect to recover their investments quickly. This rapid return on investment makes these technologies attractive options for entrepreneurs and investors, potentially accelerating the adoption of sustainable energy solutions.

Additionally, the positive economic indicators and short payback periods imply that these technologies can contribute to the growth of the renewable energy market, offering viable alternatives to traditional energy sources. The study suggests that increased adoption of these technologies could enhance energy security, reduce environmental impacts associated with conventional fuel sources, and foster local economic development through job creation and business opportunities in the bioenergy value chain.

Overall, the study not only demonstrates the economic feasibility of the improved production technologies but also highlights their potential to drive innovation and sustainability in the bioenergy sector. The results provide a compelling case for stakeholders to invest in and adopt these technologies, paving the way for a more sustainable and economically viable energy future.

6.2.2. Willingness to pay for briquette as an alternative source of energy in Nakuru

The study's findings indicate that urban residents in Nakuru County exhibit a clear preference for briquettes with specific attributes: minimal smoke production, extended burning periods, and low ash content. These preferences reflect an understanding of the factors that influence consumer satisfaction and health considerations. The strong preference for less smoke is particularly significant, as it highlights growing awareness of the health risks associated with smoke exposure. According to Tainio *et al*. (2021), prolonged exposure to smoke from burning traditional fuels is linked to respiratory problems and other health issues. Therefore, consumers' inclination towards low-smoke options underscores a shift towards more health-conscious choices in energy products. This preference suggests that producers who prioritize reducing smoke emissions in their products may gain a competitive edge in the market by addressing these health concerns effectively.

Similarly, the preference for a long burning period is driven by the practical benefits it offers. Njenga *et al*. (2013) noted that a longer burning time allows users to cook meals that require extended cooking durations, thereby enhancing convenience and efficiency in the kitchen. This aspect of product performance aligns with consumer desires for energy solutions that support their cooking needs without frequent re-fuelling, making such products more appealing.

Moreover, the lower preference for high ash content is associated with improved combustion efficiency and user comfort. As highlighted by Katimbo *et al*. (2014), reduced ash content leads to more efficient burning and less frequent maintenance, which enhances the overall user experience. Products with lower ash output are less likely to cause inconvenience during use, contributing to a more satisfactory cooking experience.

The implications of these findings are significant for stakeholders in the bioenergy sector. For manufacturers and suppliers, focusing on the development of low-smoke, long-burning, and low-ash-content briquettes can better align products with consumer preferences, potentially leading to increased market acceptance and sales. Additionally, addressing these preferences could contribute to broader public health improvements by reducing the negative effects of smoke pollution. Furthermore, these consumer preferences can guide product innovation and marketing strategies. By emphasizing the health benefits and practical advantages of their products, companies can effectively differentiate themselves in the competitive bioenergy market. This focus on consumer needs not only enhances product appeal but also supports the transition towards cleaner and more efficient energy solutions, aligning with sustainability goals and improving overall market dynamics.

6.2.3. Pathways for commercialization of bioenergy technologies and products among stakeholders in the charcoal and briquette value chain

The study highlighted several barriers to the commercialization of bioenergy technologies and products in the country. These barriers include an imbalance between the demand and supply of biofuels, inconsistent availability of biomass feedstock, inefficient information exchange among stakeholders, high capital and operational costs, technology complexity that affects reproducibility, and inadequate public policies. These challenges are categorized into market, economic, technical, and policy-related obstacles.

To overcome these barriers and unlock the commercialization potential of bioenergy, strategic interventions are necessary. Establishing public-private partnerships can play a pivotal role in addressing resource gaps, fostering collaboration, and pooling expertise and investment. Such partnerships can enhance the efficiency and effectiveness of bioenergy projects by leveraging diverse strengths from both public and private sectors. Additionally, investing in research and development is crucial for addressing technical challenges and improving the scalability of bioenergy technologies. This investment can lead to innovations that make technologies more affordable and easier to implement on a larger scale.

Furthermore, addressing policy gaps by developing supportive and coherent public policies is essential for creating a conducive environment for bioenergy commercialization. Effective policies can provide incentives, reduce regulatory barriers, and align with market needs, thus encouraging investment and growth in the sector. By focusing on these strategic areas, stakeholders can mitigate existing barriers, enhance the viability of bioenergy technologies, and drive the sector towards greater sustainability and commercial success. The study underscores the need for coordinated efforts to address these challenges, which will ultimately contribute to a more robust and thriving bioenergy market.

6.3. Conclusions

From the analyses done on each objective, conclusions can thus be made as below:

i) A successful bioenergy enterprise hinges on its economic viability, necessitating a thorough evaluation of the associated investment costs and potential returns. This study assessed the economic feasibility of various improved charcoal and briquette production technologies by analysing key economic indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period. For entrepreneurs, minimizing investment costs while achieving production efficiency is critical to ensuring sustainable profitability. The results of this study indicate that investing in improved charcoal and briquette production technologies developed by Egerton University is economically viable. All evaluated technologies yielded positive NPVs and short payback periods, highlighting their potential to deliver substantial returns on investment. These findings underscore that these bioenergy technologies not only offer a pathway to cost-effective production but also present a compelling investment opportunity for entrepreneurs in the bioenergy sector.

ii) Households in Nakuru County have a strong preference for briquettes that produce minimal smoke and sparks during cooking, reflecting their growing awareness of the health risks associated with smoke exposure. This preference indicates a shift towards healthier cooking options as households prioritize reducing indoor air pollution. Additionally, there is a high demand for briquettes with extended burning periods, which offer the convenience of cooking meals that require longer durations without frequent re-fuelling. The findings also suggest that household preferences for briquettes are influenced by socio-economic factors such as income, education, and household size, leading to variation in willingness to pay for these cleaner energy options. This heterogeneity underscores the importance of considering the diverse needs and characteristics of households when promoting briquettes as a sustainable energy solution. Understanding these preferences can guide producers and marketers in designing and positioning products that better align with consumer expectations, ultimately supporting the adoption of cleaner, more efficient cooking alternatives.

iii) Commercialization of bioenergy technologies and products is significantly influenced by a range of internal and external factors. Key barriers include market challenges, such as limited access to market information and unstable demand and supply of biomass and bioenergy products; policy obstacles like inconsistent regulations; technical issues related to the complexity and limited replicability of technologies; and economic constraints, including high capital investment and operational costs. These barriers collectively hinder the growth and adoption of bioenergy technologies within the market. However, the study also identified potential strategies to overcome these challenges and enhance commercialization efforts. Key recommendations include the development of targeted bioenergy policies that provide clear regulatory frameworks and incentives for investment in the sector. Increased funding for research and development is essential to drive innovation, improve technology scalability, and reduce production costs. Additionally, fostering public-private partnerships can facilitate resource sharing, improve market access, and support the broader adoption of bioenergy solutions. By addressing these barriers through strategic interventions, the bioenergy sector can achieve greater commercial success, contributing to sustainable energy transitions and economic growth.

6.4. Recommendations

From the findings of the study, the following recommendations could be given;

i) The profitability of a bioenergy enterprise depends on the overall investment cost of the enterprise. Developing technologies that are economically viable, especially for small-medium entrepreneurs, would attract more investors into the bioenergy value chain. The technologies could be made simpler and more user friendly to reduce costs like operation cost and repair and maintenance costs. This would also stimulate more innovations towards bioenergy sector which would help mitigate energy insecurity in Kenya.

ii) The knowledge and accessibility of bioenergy technologies and products should be spread to the general public to spur more interest. Trainings on bioenergy products like briquettes could be organized at community level to create more awareness. This would help increase uptake and utilization of bioenergy technologies and products.

iii) The government could invest more in the renewable energy sector by encouraging public-private partnerships to attract more attention from those who would wish to get into bioenergy business. Its support could also be needed to put in place low interest rates to enable easier financial access to those entrepreneurs who would wish to borrow loans from financial institutions. Government could also facilitate the development of local bioenergy factories to spur more interest from local communities to invest in the sector. Innovators could continue to evolve briquetting and charcoaling technologies to make them as economical as possible.

6.5. Further Research

This study estimated the direct benefits of briquettes and charcoal production using improved technologies. A more depth could be explored into indirect benefits of briquettes and charcoal production like the level of carbon reduction using the improved technologies which would translate to health benefits. This could be incorporated in net present value estimation. Further research could also compare the economic indicators across different scenarios for instant, comparison between the conventional production methods and production using improved technologies.

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APPENDICES

Appendix A. National Commission for Science Technology and Innovation (NACOSTI) clearance certificate

REPUBLIC OF KENYA

NACOSTI

NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY & INNOVATION

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Date of Issue: **25/January/2023**

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Appendix B. Publication

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Journal of Development and Agricultural Economics

Full Length Research Paper

Determining the pathway for commercialization of bioenergy technologies and products among stakeholders in the bioenergy value chain in Baringo County, Kenya

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Bioenergy has emerged as a suitable alternative to fossil fuels with a potential to significantly contribute to the country's energy targets. However, the well-established fossil fuel industry presents a challenge for the development of a commercially viable bioenergy industry. Other factors such as government policies, financial constraints, lack of stakeholders' coordination, technical complexities, and market chain barriers also contribute to the stagnation of the sector. This paper analyzes these barriers, existing opportunities to overcome the barriers and proposes a pathway to commercialize bioenergy technologies. The research placed stakeholders of the bioenergy value chain as the focus of the analysis, thus complementing the existing literature, and giving it a user-centered approach. Data was collected through semi-structured interviews and interactive focus-group discussions allowing stakeholders to share their experiences and perspectives. The analysis of the barriers to bioenergy expansion helped to identify opportunities to improve policy design and implementation, and address financial constraints and technological difficulties. This study's findings are relevant for developing transition strategies to low-carbon energy futures in Kenya and other developing countries that are struggling with energy transitions.

Key words: Bioenergy, commercialization, stakeholders, sustainability, Kenya.

INTRODUCTION

Bioenergy is regarded as the next major source of renewable energy alternative to fossil fuels. It is a major driving force to climate change mitigation which will ensure sustainability of the energy industry (Chan, 2018). Studies have noted that the development of sustainable energy sources and mitigation of climate change effects depend largely on the development of the bioenergy sector at a commercial scale (Parra et al., 2023; Smith and Porter, 2018). The bioenergy sector has the capacity to supply approximately 15% of the world's energy demand come 2050 (Fischer and Schrattenholzer, 2001; Parra et al., 2023). Bioenergy presents a form of renewable energy that is derived from organic/inorganic substances (Shane et al., 2017). The bioenergy industry is a vital component that will enable transition from fossil (Morone and Yilan, 2020) and contribute to the

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Appendix C. Questionnaire

EGERTON UNIVERSITY

SECTION A: HOUSEHOLD IDENTIFICATION

The Kenya Climate Smart Agriculture Project (KCSAP), seeks to promote Good Agricultural Practices across all the Agricultural Value Chains. The project through Egerton University, has disseminated different briquetting and charcoaling technologies across Baringo county. The briquettes and charcoal produced in Baringo are believed to be sold in Nakuru being the nearest largest town to Baringo. The survey therefore seeks to determine if you as the user of charcoal is **willing to pay for briquettes as an alternative source of energy for your household**, as a way to promote Climate Smart Entrepreneurship. Your participation is completely voluntary, and the information given will be treated confidentially and will only be used for academic purpose with no inclusion of a specific name. Kindly tick against your preference or write in the spaces provided.

Questionnaire Number ____________
Name of the Enumerator ___________________________________
Date ________________ Starting Time Finishing Time
Questionnaire Number
Name of the Enumerator
Date Starting Time Finishing Time

GEOGRAPHICAL LOCATION

WARD: …………………………**Ward**

1= Shabaab
2= London
3= Kaptembwo

SECTION A: DEMOGRAPHIC INFORMATION

1. Gender of HH (Household Head): 1= Male [ ] 0= Female[ ] **HHGen**
2. Age of HH (Years)…………………. **HHAge**
3. Education Level of HH………………**HHEduc**

Education level (Educ) Codes: *0= None formal education1=Primary Certificate 2= Secondary certificate 3= Tertiary education*

4. What is the size of the HH: …………………………?**HHSize**
5. What is the occupation of the HH …………………? **HHoccu**
6. What is the average level of Income of HH (KSH): …………? **IncHH**
7. Who makes the decision concerning the household? ………… **DecMaker**

   1=HH 2=Spouse 3=Both

Average Income level codes:*1=Below 10,000 2=10000 – 20000 3=20000- 40000 4= 40000-60000 5= 60000-80000 6= 80000-100000 7=Above 100000*

SECTION B: ENERGY PREFERENCE

1. What is your most preferred source of energy? …………………………**PrefEner.** Check where appropriate.

1= woodfuel [ ] 2= Charcoal 3= Liquefied Petroleum Gas (LPG) [ ] 4= Paraffin [ ] 5= Electricity[ ]

2. Why do you prefer the energy source named in question 1 above?
   i. ………………………………………………………………………………
   ii. ………………………………………………………………………………
   iii. ………………………………………………………………………………
   iv. Other reason……………………………………………………………………...
3. What is the cost of your most preferred source of energy (KS/per month)?.........................**CoPref**

SECTION C: BRIQUETTE USE

1. Do you know briquettes? **BriqKno**1=*Yes [ ] 0=No [ ]*
2. Have you used briquettes before? **BriUseB**

   1=Yes [ ] 0=No [ ]

If your answer is 'Yes' in the question above, proceed to question 2 and if 'No' proceed to question 10.

3. What was your experience using briquettes? **BriExp**

1=Very Good [ ]   2=Good [ ] 3=Average [ ]   4=Bad [ ]   5=Very Bad [ ]

4. How do you rate briquette availability in Nakuru Town? **BriqAvv**

1= Accessible [ ]   2=Rarely [ ]   3=Not Accessible [ ]

5. Did you find briquette comfortable to use? **BriqComfort***1=Yes [ ] 0=No [ ]*

SECTION C: BRIQUETTE PERCEPTION?

6. Tick in the appropriate box.

i. Is briquette easy to store? **StorEase***1=Yes[ ] 0=No [ ]*

ii. Does briquette produce a lot of ash**? AshProd***1=Yes[ ] 0=No [ ]*

iii. Does briquette produce a lot of smoke? **SmokeProd***1=Yes [ ] 0=No [ ]*

iv. Does briquette have a long burning period? **BurPeriod***1=Yes[ ] 0=No [ ]*

v. Does briquette produce high heat temperatures? **HeatTemp***1=Yes[ ] 0=No [ ]*

vi. Is it easy to light briquette? **LightEase***1=Yes[ ] 0=No [ ]*

vii. Is briquette cost high compared to charcoal? **BriCost***1=Yes[ ] 0=No [ ]*

7. Do you think you can now refer briquettes with friends and family? **BriqRef**
1=Yes[ ] 0=No [ ]

8. How did you get to start using briquette? **UseStart**

1=Its low cost[ ] 2=Its burning period [ ] 3=Trying for the first time [ ] 4=A way to help reduce environmental degradation [ ] 5=Was recommended to by somebody [ ]

9. Did you have any concerns when you started using briquettes? **UseConcern***1=Yes[ ] 0=No [ ]*

If yes, which one?

…………………………………………………………………………………………
…..

SECTION D: BRIQUETTE AWARENESS

10. What have you heard about briquettes?

i. Briquette easy to store. **StorEase***1=Yes 0=No [ ]*

ii. Briquette produce a lot of ash. **AshProd***1=Yes 0=No [ ]*

iii. Briquette produce a lot of smoke. **SmokeProd***1=Yes 0=No [ ]*

iv. Briquette have a long. **BurPeriod***1=Yes 0=No [ ]*

v. Briquette produce high heat temperatures. **HeatTemp***1=Yes 0=No [ ]*

vi. It is easy to light briquette. **LightEase***1=Yes 0=No [ ]*

vii. Briquette cost is high compared to charcoal. **BriCost***1=Yes 0=No [ ]*

11. Why do you not use briquettes? **NoUse**

1= Briquettes are not accessible [ ] 2=Briquettes are expensive [ ] 3=I have no problem with my current source of energy [ ] 4=It is hard to use briquettes [ ] 5=I don't use any form of charcoal [ ] 6=Briquette use will ruin my self-image [ ] 7=I have never heard of briquettes [ ] 8=Other [ ]

12. Have the characteristics you have heard in 10 above influenced your decision not to use briquette? **DecInfluence***1=Yes 0=No*[ ]

13. Are you willing to spend your money to purchase briquettes? 1=Yes 2=No 3=Maybe

14. To what extent do you think you influence your household energy use? **UseInflu**
1=Low [ ] 2=Average [ ] 3=Large [ ]

End.

Thank you for your cooperation!!!

SECTION 2: CHOICE EXPERIMENT

The choice cards below are generated based on attributes and attribute levels of biomass briquettes. Each card consists of two options (option A and B) and the status quo option showing a consumer who does not choose any of the options. A respondent will be required to select only one option from each of the 2 choice sets. This experiment will help determine the optimal option for biomass briquette. Choice scenarios are repeated 4 times with slight changes in the attributes in each option.

Attribute	**Description**	**Attribute Level**
Smoke/spark	Whether briquettes produce smoke and/or sparks during burning	Yes No
Heat Value	Amount of energy released as heat as briquette undergoes combustion	High (6000Kcal/kg) Low (4000Kcal/kg)
Burning Period	The period it takes the briquette to burn to ashes in a cook stove	Long (75minutes) Short (45minutes)
Ash Content	Amount of powdery residue remaining after the combustion of briquette	High (>6%) Low (<6%)
Price (KES/50kg bag)	Price for every 50kg bag of briquettes	2000, 2500, 3000

Profile 1

Choice Set 1

Briquette Attributes	**Option A**	**Option B**	**Neither A nor B**
Smoke/Spark	Yes	No	
Heat level	High (6000Kcal/kg)	Low (4000Kcal/kg)	
Burning period	Long (75minutes)	Short (45minutes)	
Ash content	High (>6%)	Low (<6%)	
Price (KES/50kg bag)	2000	2500	
Which briquette attribute option would you prefer?			

Choice Set 2

Briquette Attributes	**Option A**	**Option B**	**Neither A nor B**
Smoke/Spark	No	Yes	
Heat level	Low (4000Kcal/kg)	High (6000Kcal/kg)	
Burning period	Short (45minutes)	Long (75minutes)	
Ash content	Low (<6%)	High (>6%)	
Price (KES/50kg bag)	2000	3000	
Which briquette attribute option would you prefer?			

Profile 2

Choice Set 1

Briquette Attributes	**Option A**	**Option B**	**Neither A nor B**
Smoke/Spark	No	Yes	
Heat level	Low (4000Kcal/kg)	High (6000Kcal/kg)	
Burning period	Long (75minutes)	Short (45minutes)	
Ash content	High (>6%)	Low (<6%)	

Price (KES/50kg bag)	2000	2500	
Which briquette attribute option would you prefer?			

Choice Set 2

Briquette Attributes	**Option A**	**Option B**	**Neither A nor B**
Smoke/Spark	Yes	No	
Heat level	Low (4000Kcal/kg)	High (6000Kcal/kg)	
Burning period	Short (45minutes)	Long (75minutes)	
Ash content	High (>6%)	Low (<6%)	
Price (KES/50kg bag)	2000	3000	
Which briquette attribute option would you prefer?			

Profile 3

Choice Set 1

Briquette Attributes	**Option A**	**Option B**	**Neither A nor B**
Smoke/Spark	Yes	No	
Heat level	Low (4000Kcal/kg)	High (6000Kcal/kg)	
Burning period	Long (75minutes)	Short (45minutes)	
Ash content	Low (<6%)	High (>6%)	
Price (KES/50kg bag)	2500	3000	
Which briquette attribute option would you prefer?			

Choice Set 2

Briquette Attributes	**Option A**	**Option B**	**Neither A nor B**
Smoke/Spark	No	Yes	

Heat level	High (6000Kcal/kg)	Low (4000Kcal/kg)	
Burning period	Short (45minutes)	Long (75minutes)	
Ash content	High (>6%)	Low (<6%)	
Price (KES/50kg bag)	2500	2000	
Which briquette attribute option would you prefer?			

Profile 4

Choice Set 1

Briquette Attributes	**Option A**	**Option B**	**Neither A nor B**
Smoke/Spark	Yes	No	
Heat level	High (6000Kcal/kg)	Low (4000Kcal/kg)	
Burning period	Short (45minutes)	Long (75minutes)	
Ash content	Low (<6%)	High (>6%)	
Price (KES/50kg bag)	2000	2500	
Which briquette attribute option would you prefer?			

Choice Set 2

Briquette Attributes	**Option A**	**Option B**	**Neither A nor B**
Smoke/Spark	No	Yes	
Heat level	High (6000Kcal/kg)	Low (4000Kcal/kg)	
Burning period	Long (75minutes)	Short (15-45minutes)	
Ash content	Low (<6%)	High (>6%)	
Price (KES/50kg bag)	3000	2000	

Appendix D: Key Informants Interview

EGERTON UNIVERSITY

I am a student at Egerton University, pursuing Master of Science in Agri-Enterprise Development. I am conducting a research on the Opportunities Existing for Commercialization and Upscaling of Briquettes in Baringo county. The results of this study will help in environmental conservation, present agribusiness opportunities for the youth and community members and provide recommendations for the county and national government to roll out projects that would help ensure briquettes are widely adopted in Kenya and beyond. Your participation is highly appreciated and the answers you give will be treated with high confidentiality. This interview will take **30-45 minutes.** Kindly give response to the following questions based on your views.

Organization………………………………………………….

Sector ………………………………………………………

Designation…………………………………………………

Organization's major activity…………………………………………………….

Interviewer's Name……………………………………………………………...

Q1. Which Climate Smart initiatives do you promote and why?

Q2. Which group of people do you target?

Q3. What are your dissemination strategies?

Q4. How many climate smart technology initiatives exist in Baringo/Nakuru that you are aware of?

Q5. From your own perspective, what strategies can be used to enhance bioenergy climate smart technology adoption by the wider population?

Q6. What challenges hinders communities from uptaking bioenergy climate smart technologies??

Q7. Could you give potential solutions for the challenges you have mentioned that could help steer the industry.

Q8. What policies hinder the uptake of bioenergy climate smart technologies?

Q9. What policies do you think should be put in place to support widespread uptake of bioenergy climate smart technologies and products?

Thank You!

Appendix E: Entrepreneurs Focus Group Discussion

EGERTON UNIVERSITY

I am a student at Egerton university pursuing Master of Science in Agri-enterprise development. I am carrying out research on “Fostering Climate Smart Entrepreneurship among Small and Medium Entrepreneurs in Baringo and Nakuru counties”. Through KCSAP project, bioenergy technologies have been disseminated to your group as a way to promote environmental conservation and improve charcoal and briquettes production in the region. The following are some of the questions concerning your experience with the technologies. Your answers will highly be appreciated and will be treated with high confidence.

Group name……………………………………………………………….

Section A: Technology Use

1. What type of technology is your group promoting?

   ………………………………………………………………………………..
2. What type of technology did you use previously?

   ……………………………………………………………………………….
3. What are your experiences/challenges with your previous production methods?
   - i. ……………………………………………………………….
   - ii. ………………………………………………………………………
   - iii. ………………………………………………………………………
4. What are your experiences with the new technology?
   - i. …………………………………………………………………………
   - ii. …………………………………………………………………………
   - iii. …………………………………………………………………………
   - iv. …………………………………………………………………………
5. What challenges do you experience with regards to production, marketing and transportation of your bioenergy products?
   - i. …………………………………………………………………………
   - ii. …………………………………………………………………………
   - iii. …………………………………………………………………………
   - iv. …………………………………………………………………………

6. What government policies/restrictions have you experienced that have affected or promoted your enterprises?
7. What do you think can be done to promote widespread us of the technology?

……

Thank You for Your Cooperation!!

Appendix F: BCST investment checklist

This checklist enabled the researchers to note all the requirements in the operation of the technologies.

Technology Name and Use…………………………………………………………………….

a. What are the raw material and quantity needed in production of briquettes/charcoal using the technology?
b. What is the cost of each material used in production?
c. What is the cost of labour required for production?
d. What is the production time?
e. What quantity of charcoal/briquette is produced?

Appendix G: Egerton university charcoaling and briquetting technologies

(a) **(b)**

Charcoaling technologies (a) Vertical drum kiln (b) Horizontal drum kiln

(a) (b)

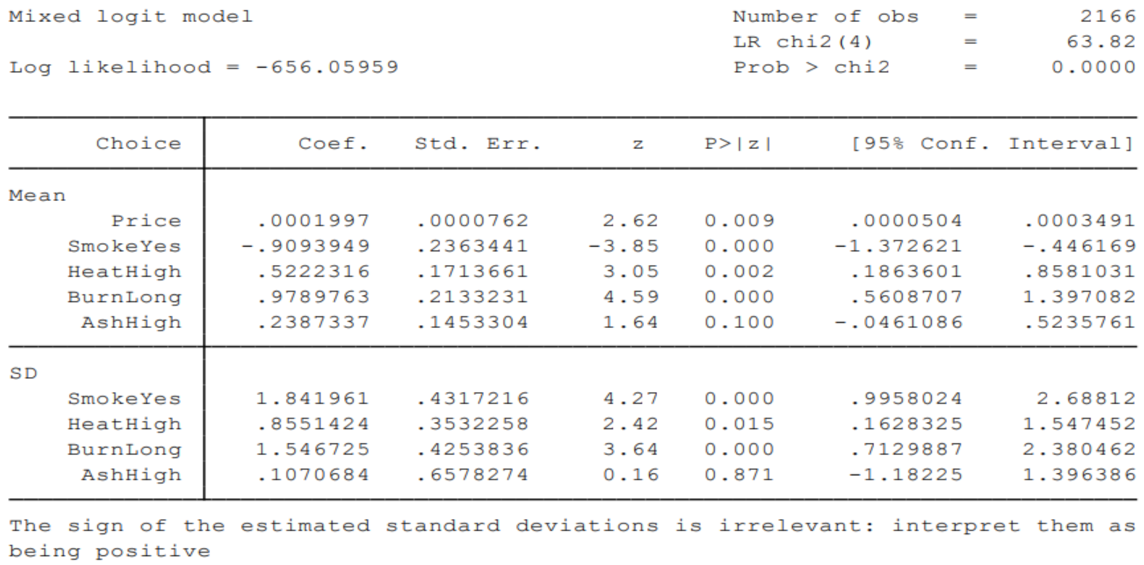
Briquetting technologies (a) Drum agglomerator (b) Screw press

Appendix H: Cost of briquettes production

Total Cost of Briquettes Production for Drum Agglomerator and Screw Press at production capacity of 50kg/h and 25kg/h respectively

Item	**Rate (KES)**		**Amount (KES)**	
	Drum Agglomerator	**Screw Press**	**Drum Agglomerator**	**Screw Press**
(A) Fixed Cost (Initial Investment)				
A1. Briquette machine	150,000	100,000	150,000	100,000
A2. Installation cost	2,000	2,000	2,000	2,000
A3. Storage facility cost	12.5/h×8h/day×240days	12.5/h ×8h/day×240days	24,000	24,000
Sub-total			176,000	126,000
(B) Operation Cost				
B1. Raw material cost	131.04/h×8h/day×240days	105.52/h×8h/day×240days	251,596.8	202,598.4
B2. Raw material processing	600/day×240days	500/day×240days	144,000	120,000
B3. Labour cost	600/day×240days	500/day×240days	144,000	120,000
B4. Electricity cost	125/h×8h/day×240days	125/h×8h/day×240days	240,000	240,000
B5. Depreciation cost	10% of Initial Investment (A)	10% of Initial Investment (A)	17,600	12,600
B6. Miscellaneous cost	5% Sum of (B1; B2)	5% Sum of (B1; B2;B3)	26,979.84	22,129.92
Sub-total			824,176.64	717,328.32
(C) Repair and Maintenance cost				
C1. Repair and maintenance cost	10% of A	10% of A	17,600	12,600
Sub-total			17,600	12,600
Total Investment Cost			**1,017,776.64**	**855,928.32**

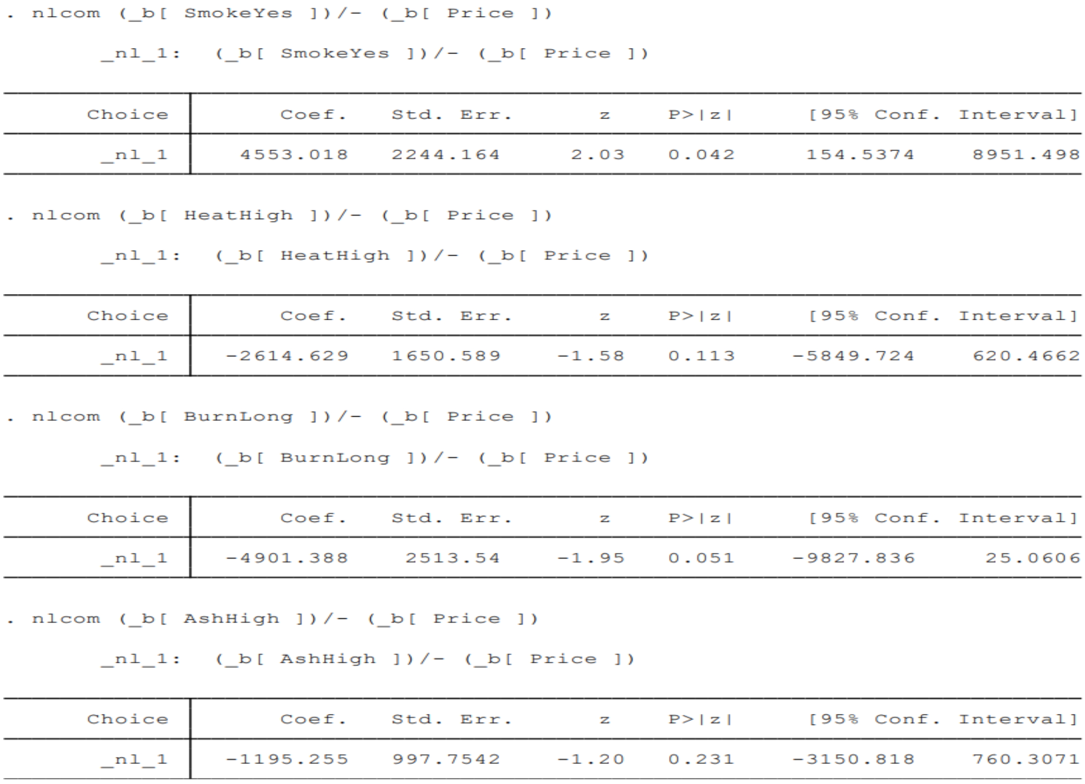
Appendix I: Results of mixed logit regression analysis on consumers’ preference for briquettes



```
Mixed logit model                                 Number of obs   =       2166
                                                  LR chi2(4)      =      63.82
Log likelihood = -656.05959                       Prob > chi2     =     0.0000

------------------------------------------------------------------------------
      Choice |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
Mean         |
       Price |   .0001997   .0000762     2.62   0.009     .0000504    .0003491
    SmokeYes |  -.9093949   .2363441    -3.85   0.000    -1.372621    -.446169
    HeatHigh |   .5222316   .1713661     3.05   0.002     .1863601    .8581031
    BurnLong |   .9789763   .2133231     4.59   0.000     .5608707    1.397082
     AshHigh |   .2387337   .1453304     1.64   0.100    -.0461086    .5235761
-------------+----------------------------------------------------------------
SD           |
    SmokeYes |   1.841961   .4317216     4.27   0.000     .9958024     2.68812
    HeatHigh |   .8551424   .3532258     2.42   0.015     .1628325    1.547452
    BurnLong |   1.546725   .4253836     3.64   0.000     .7129887    2.380462
     AshHigh |   .1070684   .6578274     0.16   0.871     -1.18225    1.396386
------------------------------------------------------------------------------
The sign of the estimated standard deviations is irrelevant: interpret them as
being positive
```

Appendix J: Willingness to pay for attributes using Hole's wtp command (delta method-nlcom command)



```
. nlcom (_b[ SmokeYes ])/- (_b[ Price ])

       _nl_1:  (_b[ SmokeYes ])/- (_b[ Price ])

------------------------------------------------------------------------------
      Choice |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       _nl_1 |   4553.018   2244.164     2.03   0.042     154.5374    8951.498
------------------------------------------------------------------------------

. nlcom (_b[ HeatHigh ])/- (_b[ Price ])

       _nl_1:  (_b[ HeatHigh ])/- (_b[ Price ])

------------------------------------------------------------------------------
      Choice |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       _nl_1 |  -2614.629   1650.589    -1.58   0.113    -5849.724    620.4662
------------------------------------------------------------------------------

. nlcom (_b[ BurnLong ])/- (_b[ Price ])

       _nl_1:  (_b[ BurnLong ])/- (_b[ Price ])

------------------------------------------------------------------------------
      Choice |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       _nl_1 |  -4901.388    2513.54    -1.95   0.051    -9827.836     25.0606
------------------------------------------------------------------------------

. nlcom (_b[ AshHigh ])/- (_b[ Price ])

       _nl_1:  (_b[ AshHigh ])/- (_b[ Price ])

------------------------------------------------------------------------------
      Choice |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       _nl_1 |  -1195.255   997.7542    -1.20   0.231    -3150.818    760.3071
------------------------------------------------------------------------------
```