TECHNOLOGICAL FACTORS INFLUENCING THE QUALITY AND QUANTITY OF CHARCOAL PRODUCED IN WESTERN MAU FOREST, KERICHO COUNTY, KENYA

Ivy Maledi Amugune

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DECLARATION

I declare that this document and the research that it describes are my original work and that they have not been presented in any other University for academic work.

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Ivy Maledi Amugune
18J03EMEV002

This research was conducted under our supervision and is submitted with our approval as University supervisors

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Dr. Mark Ndunda Mutinda

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Dr. David Kipkirui Langat

AFRICA NAZARENE UNIVERSITY,
NAIROBI, KENYA

DEDICATION

This thesis is dedicated to my beloved mother, Vestina Amugune, for her support and encouragement throughout my studies and for her wise words of wisdom “Never give up, there is always a light at the end of the tunnel” and for sure there is.

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ABSTRACT

Charcoal is a key bio-energy resource in Kenya, providing domestic energy for 82% of urban and 34% of rural households. The charcoal industry also creates jobs for wood producers, charcoal producers, transporters and vendors. The industry employs almost 1 million people on a part and full-time basis across the value chain. Despite regulation there is continued unsustainable charcoal production in western Mau forest block. Are the regulations not working or simply not implemented by the mandated authority? Different studies over the years have shown how unsustainable charcoal production affects the forest, in other parts of the Mau region like in Narok and Nakuru. The western part of Mau forest, which is in Kericho region is noticeably depleted. The study therefore aimed at assessing technological factors that influence the quality and quantity of charcoal within the western Mau forest. Specifically, the study sought to evaluate the effects of tree harvesting methods, method of carbonization, tree species on quantity and quality of charcoal produced. A descriptive research design was adopted and targeted the local actors who were involved in charcoal business in areas adjacent to the western Mau Forest in Kericho County. The areas under study were Kedowa/Kimugul, Chepseon, Ainamoi and Kaorora, Kapsuser, Kapkatet, Nyagacho, Kericho Kapsoit, Londiani and Litein. This study employed snowball sampling technique to reach the target respondents. Primary data were collected using different set of structured questionnaires. Descriptive statistics such as frequencies, percentages, mean scores, standard deviation, cross tabulations and charts were derived from the responses to summarize data from various variables. Inferential statistics were applied using the correlations and chi-square tests. The results showed that simple tools like machete and axe were commonly used to harvest trees illegally in the western Mau forest. The majority (87 %) of the charcoal producers used earth mound kiln because the kiln was simple to build, and the materials used were easily available and affordable. The majority of producers perceive that indigenous species produces best charcoal, but in reality, the majority went for exotic species exclusively, while others mixed indigenous and exotic species. The most preferred indigenous species were *Olea africana*, *Euclea divinorum*, *Acacia lahai* and *Acacia seyal*, while the preferred exotic species were *Cupressus lusitanica*, *Eucalyptus saligna* and *Eucalyptus ficifolia*. The plant species selected was found to significantly ($p<0.05$) influence the quality and quantity of charcoal produced. The harvesting techniques used influenced the quality quantity of the charcoal produced. Two factors were significant the size of the billets and the dryness of the wood influenced the quality and quantity. The carbonization technique used significantly ($p<0.05$) influenced the quality and quantity of charcoal. The traditional earth mound used by most producers produced low quantity and poor quality charcoal compared to the metal and cut drum techniques. It was recommended that the government and relevant organizations should facilitate forest plantations for charcoal production and fuel wood purposes. This will deter charcoal producers from going into the government forest to produce charcoal. The charcoal producers should exploit the current best practices and technology in charcoal production.

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LIST OF ABBREVIATIONS AND ACRONYMS

CPA	Charcoal Producer Associations
CTL	Cut-to-length
CVC	Charcoal Value Chain
ECC	Environment County Conservator
FT	Full tree
ICRAF	International Centre for Research in Agro-Forestry
MEWNR	Ministry of Environment, Water and Natural Resources
MFC	Mau Forest Complex
NAFA	Natural Forestry Authority
NTFPs	Non - Timber Forestry Products
SNV	Netherlands Development Organization
TL	Tree Length

DEFINITION OF TERMS

Charcoal Refers to a solid residue derived from the carbonization, distillation, pyrolysis and to refraction of wood (trunks and branches of trees) and wood by-products, using continuous or batch systems (pit, brick and metal kilns) (ESDA, 2005)

Charcoal value chain Is a process or stages of charcoal industry from production to consumption (Blodgett, 2011)

Earth Mound Kiln Refers to a traditional system that involves a pile of wood in the form of flattened hemisphere on a grid of cross logs to allow air circulation, is built on a cleared area, The pile is covered with leaves and grass followed by a layer of sand or sandy loam to a thickness of about 10-12 cm (Puentes-Rodriguez et al., 2017)

Tree harvesting methods Refers to the assortments or form in which wood is delivered to the mill or end user. Common types of harvesting methods are cut-to-length (CTL), tree length (TL) and full-tree (FT) (MacDonald & Clow, 1999).

Tree Species Refers to various trees specifically used for charcoal production (Okoko et al., 2018).

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This study was an assessment of the technological factors influencing the quality and quantity of charcoal produced in Western Mau forest, Kericho County. The independent variables were the technological factors involved in the production of charcoal, they included: tree harvesting, carbonation methods, and the tree species used in charcoal production. The dependent variable was the quality and quantity of charcoal produced in Western Mau forest in Kericho county.

This chapter introduces the topic under study, how technological factors influence charcoal production in western Mau forest, Kericho County. The chapter contains background of the study, statement of the problem, purpose of the study, study objectives, research questions, significance of the study, delimitations and limitations, assumptions of study, theoretical frame work and conceptual framework.

1.2 Background of the Study

Humankind's first source of energy is considered to be wood fuel (Hosier, 1993). Fuel wood and charcoal are the most globally used for energy supply. Wood is an important type of biomass, with annual global utilization at 3.3 billion m3, of which more than half is used for energy (FAO, 2007). The use of natural wood charcoal is approximately dated back to 30,000 years ago commonly in cave drawings (van Beukering et al, 2007). Over 2 billion people globally rely on fuel wood as their main energy supply, especially rural households in developing countries (FAO, 2010). Wood charcoal production globally was in the year 2009, estimated at 47 million metric tons; 9% increase since 2004 (FAO 2009). Fuel wood and charcoal provide more than 14% of the world's total primary energy and more significantly in developing countries (ibid). This demonstrates the importance wood-fuel plays in meeting the energy requirements of developing countries.

Charcoal, timber and other Non-Timber Forest Products (NTFPs) are part of a broad range of woodland resources providing direct benefits to rural and urban livelihoods (Gumbo et al., 2013). The African continent uses more than 90% of harvested wood for energy production, and about 30% of fuel wood extracted is used directly for charcoal production, which is expected to increase within the next twenty years (FAO, 2016). The high demand for fuel wood in developing countries is due to the relatively high cost of electricity, low capacity of electricity production and petroleum-based fuels, and rapid human population growth, particularly in urban areas. Charcoal production is fueled by increasing energy needs of the cities; the limited availability of affordable energy alternatives in the main cities, and high levels of poverty in rural areas.

Charcoal production and trade provides employment to millions of people in Africa due its prominence as the main cooking fuel in many African urban centers and increasing demand because of population growth and migration from rural to urban areas (International Energy Agency [IEA], 2014). In rural areas, of Sub-Saharan African countries (where 80% of residential energy demand is for cooking) more than 90% of the population uses firewood for cooking and less than 5% use charcoal. In urban areas, the figures change to 25% relying on firewood and nearly 50% on charcoal (IEA, 2014). Charcoal is an important woodland based energy for African rural populations, but also can be a driver of deforestation and forest degradation through intensive and selective wood extraction (Ryan, Berry & Joshi, 2014).

In sub-Saharan countries such as Mozambique, 15% of the population participates in the charcoal market, which is estimated to have an annual value of 250 million USD. Around 70 to 80% of the urban population uses charcoal as primary energy source and the demand is rising with rapid urban population growth (IEA, 2014). Charcoal production in Mozambique is affected by a range of factors similar to most sub-Saharan countries. Policy effectiveness suffers from limited institutional cooperation, integration and coordination between related sectors (Zulu & Richardson, 2017). Concerning the distribution of benefits from the charcoal value chain, large part of charcoal derived income goes to non-local individuals due to communities' lack of technical, institutional, and financial capacity (Sitoe, Salomão & Wertz-Kanounnikoff, 2017).

In Angola, about 62.3% of the population lives in urban areas and the rural areas represent the remaining proportion, this significant part of the population inhabiting the rural areas relies on fuel wood extraction, charcoal production and other Non-Timber Forest Products (NTFPs) as a principal source of income and subsistence (INE, 2016). The annual demand for fuel wood and charcoal in the country is estimated at 6 million m^3 yr^{-1} (MINADER, 2006). Around 3 million people in Ghana have their livelihood source in the charcoal sector, with more than 50 percent of these individuals being women. In Uganda, about 2 million people have a permanent source of earnings from charcoal operations. A survey carried out in Tanzania, Dar-Salaam, for example, suggested that the processing and trade of charcoal provided jobs for hundreds of thousands of locals.

In Kenya, the charcoal sector has acquired considerable economic importance because of increasing urbanization. According to the comprehensive national charcoal survey undertaken in 2004 by ESDA the total annual charcoal consumption is estimated at 1.6 million tonnes, generating an estimated annual market value of over Kshs 32 billion (US$427m), almost equal to the Kshs 35 billion (US$467m) from the tea industry (Mutimba & Barasa 2005). About a quarter of household income in Kenya is spent on wood fuel, usually regarded as the poor person's energy source, since the alternative energy sources are beyond the means of most Kenyans (Kituyi, 2002).

The industry also contributes to government revenues through licenses and business permits. For instance, PISCES (2010) reported a fee of 20 shillings and 1800 per bag and per lorry load of charcoal respectively being charged by the Kitui county council. The study by ESDA (2005) reported a fee of between 30 to 50 shillings per bag of charcoal collected by county councils. The report by (Mutimba & Barasa, 2005) demonstrated the potential government revenue of over KES 5.1 billion if sufficient efforts were invested in effective collection. The study indicated that, if cases were charged on all the estimated 60 million bags of charcoal traded within the country, the country would generate an additional Kshs 1.8 billion to Kshs 3 billion Annually.

1.1.1 The Charcoal Value Chain

The charcoal value chain starts where the tree grows, wood harvesting to eventual consumption. It includes all the economic activities undertaken between in the production to consumption system. Many different stakeholders participate in the value chain; right from wood production, carbonization of the wood, packaging and transportation of the charcoal, retailing and distribution, and consumption. A brief review of literature of charcoal value chain analysis within the region helps identify the main actors and understand their roles and main activities.

In a study aimed at generating data on the profits and margins along Uganda's charcoal value chain, Shively *et al.* (2010) identified five major roles for value chain participants: producer, agent, transporter, trader, and retailer. This was confirmed by another study aimed at understanding key players along the timber and charcoal value chain in selected districts in Uganda (Kakuru, 2012). This study identified tree farmer/landowner and forest authorities at the local level in the wood production section, charcoal producers in harvesting and charcoal production, transporters and Traders (retail and wholesale) in the transport, distribution, retail and wholesale trade section and households and institutions in the consumption section.

A study of charcoal consumption, trade and production in Malawi (Kambewa, *et al*., 2007) revealed several scenarios dependent on the route followed by charcoal from the producer to consumer. The first scenario was from producer to consumer, whereby a small-scale producer takes the charcoal directly to the consumer. The second scenario was from producer to buyer to consumer, where a buyer purchases the charcoal from the producer and takes it directly to consumers' homes. The third scenario was from producer to primary buyer to secondary buyer to consumer which was a more complex option with wholesalers and retailers. According to the authors, the last scenario was most common in Blantyre and Lilongwe where there were well-established wholesale markets, especially in high-density, informal settlements.

The charcoal value Chain and improved cook stove sector analyses commissioned by SNV in December 2010 for Rwanda, identified five key actors in the wood production component of the charcoal value chain (CVC): wood producers, local authorities, National Forest Authority (NAFA) District Officer, financial services providers and research institutions. Within the carbonization section of the CVC, the analysis found main stakeholders are charcoal producers, local authorities, middlemen, financial services providers, communication enterprises and research institutions. A further analysis of the CVC identified transporters, community police and middlemen as the key stakeholders in the transportation section. The analysis also identified charcoal retailers, local authorities and landlords as main stakeholders in the retail and distribution section. A clear definition of the roles and activities of each stakeholder based on the above and other reviews is presented in Table 1.1 (See Appendix VI).

1.1.2 Global Perspective for Charcoal Production and Value Chains

The global production of wood charcoal was estimated at 47 million metric tons in 2009-an increase of 9% since 2004 (FAO, 2010). This main contribution to this increase was Africa, which produced about 63% of the global charcoal production (FAO, 2010). Charcoal production has increased in Africa by almost 30% since 2004, making it the global leader in charcoal production (FAO, 2010). The escalating rate of wood charcoal production, particularly in developing countries, will continue to pose severe threats on the remnant woodland resources.

1.1.3 Regional Perspective for Charcoal Production and Value Chains

A review was conducted to assess the charcoal production systems and charcoal value chains in Rwanda, Malawi and Uganda. Rwanda is reported to be one of the few countries with increasing forest cover with an increase of about 7% from 2000 to 2005 due to large numbers of forest plantations. Rwanda's charcoal production system is characterized by high timber and wood fuel prices due to massive prior deforestation. Most of the charcoal is derived from trees planted on government, private or community land. Charcoal production is no longer being produced from natural forests and the remaining rainforests are well conserved. There exists secure land tenure and improved market control and negotiation power of farmers/ charcoal producers. Due to the rising income, there is improved social standing of farmers in rural society (NL Agency, 2011).

In Uganda, charcoal is produced mainly from woodlands which constitute roughly 3,975,000 hectares or 81 percent of Uganda's total forested area. Charcoal production is concentrated in central Uganda and parts of western and northern Uganda, with the main species utilized for production being; *Combretum; Terminalia; Albizia; Acacia; Allophylus* and *Grewia spp.* These woodlands are characterized by low rainfall and charcoal production is undertaken as the primary activity by the locals or at times as a complement to land clearing which produces large volumes of raw material suitable for conversion to charcoal (Shively, *et al.*, 2010). Most of the charcoal produced in these areas is transported to Kampala city. There is lack of control at all levels in the value chain due to the weak capacities of the forest authorities (Kakuru, 2012).

In Malawi, 60% of the charcoal consumed in the major urban areas including Blantyre City, Lilongwe City, Mzuzu City and the Municipality of Zomba are mainly produced from Forest Reserves and National Parks. Forty percent (40%) of charcoal from customary land and only 2% of charcoal come is sourced from Mozambique. Charcoal is primarily produced using traditional earth kilns which is wasteful and inefficient and has been found to alter the species composition of forests (Kambewa, *et al* 2007).

In all the three countries, the industry provides substantial employment for those involved in charcoal production, transportation and trade. In Rwanda, surveys in 2010 indicate the sector employed more than 300, 000 people in wood production, and 8,000 people in charcoal production, with a further 200 to 300 people involved in transportation (Blodgett, 2011). In Uganda, around 200,000 permanently earn money from charcoal ESD (2007). In Malawi, a study by Kambewa, *et al* (2007) estimated that 92,800 people are dependent on charcoal for their livelihoods. This included 46,500 producers, 12,500 bicycle transporters, 300 other transporters and 33,500 traders.

In terms of revenue generated, there are significant variations in the three countries. The charcoal industry revenue accounts for about 0.5% of Malawi's GDP. The approximate value of the industry in the four largest urban areas of Malawi is roughly US $41.3 million, a figure that is slightly less than the value of Malawi's tea industry (Kambewa, *et al* 2007). In Rwanda, the industry contributes to between 1.1% and 5% of its GDP (Blodgett, 2011). In Uganda, the industry's contribution to Uganda's GDP stood at Ushs 70 billion (Approximately USD 36,175,711-1 USD=1935) (Knöpfle, 2004).

Benefits are almost evenly distributed among stakeholders in the charcoal value chain in Malawi, with values accruing to producers ranging from 20% to 33% of retail price, transporters earning 20% to 25% of final value and retailers making the greatest profits of 25% to 33% of final selling price (Kambewa, *et al* 2007). A study analyzing the Profits and margins along Uganda's charcoal value chain (Shively *et al* 2010), revealed the greatest overall returns to participation in the charcoal value chain is among traders. Within the Rwandese value chain, wood production sector was valued at US$ 8.7 million, carbonization at US$ 17.5 million, transport sector at US$ 19.7 million and the retail and distribution at US$ 6.5 million (Blodgett, 2011).

1.1.4 Kenyan Perspective for Charcoal Production and Value Chains

It is estimated that 200,000 people are directly employed in production and an estimated 500,000 others involved in transportation and vending of charcoal, with estimated dependent population of about 2.5 million (Mutimba & Barasa, 2005). The report showed producers, transporters and vendors earned average annual incomes of KES 4,496, KES 11,298 and KES 7,503 respectively. Studies by GTZ (2009) reveal that producing cook stoves provides good business opportunities for producers, suggesting that an average of 337 improved cook stoves per month are produced per producer, earning them an average monthly income of US$120-US$240.

1.2 Statement of the Problem

Charcoal sector in Kenya, is very important for energy supply, but if properly managed, provide employment and a significant tax base. The fact that its production and processing take place in rural areas with fewer job opportunities reduces the rural-urban migration associated with job search a major problem in developing countries. There have been several attempts to curb unsustainable charcoal production by imposing temporary bans. This seems unworkable even though, the government has gazetted Charcoal Rules (2009), which provides guidelines on the legal requirements for producers, transporters and traders engaged in the charcoal business (Ndegwa, Anhuf, Nehren, Ghilardi & Iiyama, 2016).

Despite regulation there is continued unsustainable charcoal production in Mau west forest block. Are the regulations not working or simply not implemented by the mandated authority? Different studies over the years have shown how unsustainable charcoal production affects the forest, in other parts of the Mau region like in Narok and Nakuru (Kiruki, van der Zanden, Gikuma-Njuru & Verburg, 2017; Ndegwa et al., 2016). The Mau western part of the forest, which is in Kericho region is noticeably depleted (Kiruki, van der Zanden, Kariuki & Verburg, 2019).

Studies that have been carried out on charcoal value chain focused on the charcoal transition: greening the charcoal value chain to mitigate climate change and improve local livelihoods (Dam (2017), Charcoal supply chains from Mabalane to Maputo (Baumert et al., 2016). Locally there exist few studies on charcoal value chain, and therefore it is necessary to undertake this study to investigate the value chain activities of charcoal production and how it affected the quality and quantity of charcoal in Kericho County. The information from this study will provide a clear understanding of charcoal production to consumption system to assist in developing viable strategies to reduce local community's dependence on charcoal and therefore support sustainable management of West Mau natural forest in Kericho County. The study was undertaken with the following objectives:

1.3 General Objective

To assess how technological factors influence charcoal production in Mau West, Kericho County.

1.4 Specific Objective

The specific objectives of the study included:

(i) To determine the influence of tree species used on the quality of charcoal produced in Mau west forest, Kericho, County;

(ii) To determine the influence of tree species used on the quantity of charcoal produced in Mau west forest, Kericho, Count.

(iii) To evaluate the influence of tree harvesting techniques on the quality of charcoal produced in Mau west forest, Kericho, County;

(iv) To determine the influence of tree harvesting techniques on the quantity of charcoal produced in Mau west forest, Kericho, County;

(v) To determine the influence of carbonation techniques on the quality of charcoal produced in Mau west forest, Kericho, County;

(vi) To determine the influence of carbonation techniques on the quantity of charcoal produced in Mau west forest, Kericho, County;

1.5 Research Questions

The following are the research questions:

(i) How does the tree species selected influence the quality of charcoal produced in Mau West forest, Kericho County?

(ii) How does the tree species selected influence the quantity of charcoal produced in Mau West forest, Kericho County?

(iii) How does tree harvesting techniques influence the quality of charcoal produced in Mau West forest, Kericho County?

(iv) How does tree harvesting techniques influence the quantity of charcoal produced in Mau West forest, Kericho County?

(v) How does the carbonation techniques influence the quality of charcoal produced in Mau West forest, Kericho County?

(vi) How does the carbonation techniques influence the quantity of charcoal produced in Mau West forest, Kericho County?

1.6 Justification of the Study

A value chain is a sequence of related business activities, from the provision of specific inputs for a particular product to primary production, transformation, marketing, the final sale of a particular product to consumers (Baumert et al., 2016). It shows the links between the set of operators performing these functions i.e. producers, processors, traders and distributors of a particular product through various business transactions. In the wood energy sector, the value chain helps us to understand the economic flows between the actors. This makes it possible to gauge and interpret the importance of wood fuels in the regional or national economy, their contribution to job creation and income generation, potential for the creation of fiscal revenue and the impact of substitution of energy sources (Dam, 2017).

To achieve this, FAO recommends an analysis of the social and economic dimensions of wood fuel production, consumption, transport and trade. The economic magnitude of commercial physical flows is first mapped, followed by price chain analysis and the estimation of the contribution at each stage by the producers, transporters, wholesalers and retailers (FAO, 2016). In a publication *"Analysis of charcoal value chains - general considerations"* notes that proper value chain analysis enables policy makers to create a favorable framework conditions which promote competitive enterprises, sustainable jobs and income for local people. Kabisa et al., (2020) asserted that the evidence-based analyses of the value chain provide the opportunity to demonstrate the added value of wood fuel production and thus help to sensitize policy makers on a source of energy hitherto neglected and left to the informal sector. Despite the importance of charcoal value chain, little is known how the value chain determines the quality and quantity of charcoal, thus the need for a study on value chain activities effect on charcoal quality and quantity with special focus on Kericho County.

1.7 Significance of the Study

This study has enormous significance that ranges from the global scale to the national. In view of the continuous global call to conserve the environment against the ever-growing demand and supply of wood fuel with its attendant environmental threats, research of this sort is very crucial in achieving results that would inform the on-going discourse. The current efforts in combating global climate change are traceable to environmental shocks/imbalances. The study could contribute to the identification and formulation of local strategies, plans and programs of action for the conservation and sustainable exploitation of biological diversity.

Secondly, research shows that Mau Forest is rapidly depleting. Thus, in the last few decades, Kenya has lost close to 70 percent of its wildlife and about 75 percent of its 8.2 million hectares of forest (Resource Watch Agenda, 2019). Responsible factors for the situation include; unsustainable methods of charcoal burning, perennial bush fires, poor farming practices and logging. The research findings and recommendations could serve as important information in managing the situation.

Additionally, charcoal production is an important cross cutting issue and is never exhaustive through a single research. Therefore, this study is aimed at contributing to research on the charcoal value chain and production. The entire study could serve as one of the reference materials for future researches. This would not only promote academic successes through a contribution the body of knowledge to academics and policy makers but would also help the rural communities to sustain their livelihood. There will therefore be the likelihood of maintaining micro-economic stability at local communities. The general hope is that, government agencies including the County government in the study area could also enact effective environmental and charcoal producing by-laws based on the research findings and recommendations.

1.8 Scope of the Study

The study site was Mau West Forest, which covers an area of approximately 10,412.10 Sq. Km. in Kericho County. Specifically, the study was carried in Kedowa/Kimugul, Chepseon, Ainamoi and Kaorora, Kapsuser, Kapkatet, Nyagacho, Kericho Kapsoit, Londiani and Litein areas adjacent to the Mau West forest in the County. The selected areas continue to be the hub of charcoal production in Kericho County.

The research focused on how value chain activities affected charcoal production in Kericho County. Specifically, the study examined the effects of tree harvesting methods, earth mound kiln and tree species on quality and quantity of charcoal. The study covered the period 2019 to 2020. The period was chosen bearing in mind the fragmented/informal and rural nature of the charcoal activities which could affect recall responses.

1.9 Limitation of Study

The researcher's sole aim was to administer the questionnaires so as to enhance the high rate of returned responses from the respondents. While the study concentrated on Kenyan road transport sector in the rural areas, the researcher experienced challenges in reaching the respondents and also securing their precious time considering their busy working schedules and the moratorium in place which made majority of the producers go into hiding.

1.10 Delimitations of the Study

The research was largely based on a representative case study that is Mau West Forest. The value of a case study is that experiences are made accessible to others without actually having to be in the same place. It must be recognized that a case study provides deeper insight into the elements that play a role in the situation of that case. It was the question of: how representative is that case for other situations? Can the findings be generalized to the larger charcoal production sector? Most likely it will not. There were specific circumstances that play a typical role in the specific case of the study. Although the findings can't be generalized, they still can be seen as an example and hence will contribute to recognition, awareness and deeper insight.

An expert review, which was also involved with this research, functioned as a starting point of comparison. A comparison of the case study findings with experiences of charcoal value chain experts will indicate whether there could be a matter of generality in charcoal quality and quantity in relation to charcoal value chain.

1.11 Assumptions of the Study

The assumptions were that respondents would be transparent and would answer the survey questions truthfully.

1.12 Theoretical Framework

This section dealt with the systems theory that was found to be relevant to the study.

1.12.1 The Systems Theory

The Systems Theory was used for this study due to its relevance on value chain structure. Von Bertalanffy (1956) defines a system as a complex of interacting elements. Von Bertalanffy fosters systems thinking in all disciplines in order to find general principles valid to all systems (Mele, Pels, & Polese, 2010). One of the principles in System Theory is that a system is not static and consists of a complex whole, which interact as a structured functional unit. Another principle is that there is information flowing different composites of the system. Third principle is that systems consist of different entities, which seek an equilibrium state, and in the process, they can manifest oscillation, exponential growth or decay.

In this study, the System Theory helps explain better various components that work around intricate system of charcoal trade. The charcoal value chain is a system that has various components to it. By being able to know how the structure is and the various actor’s roles, we will be able to know the biomass influxes from the forest from charcoal production. Hence being able to know how much forest cover loss is attributed to charcoal production.

Knowledge sharing among local communities and the government through various relevant sectors on various aspects such as charcoal policies, legal framework and new technologies involved in the charcoal trade significantly may determine level of biomass energy- charcoal, exploitation in Kenya either into sustainable or unsustainable way. Local communities, entrepreneurs, government sector and private sector seem to form a pattern of complex system in charcoal production and trade. While the government imposes laws that seek to regulate unfair exploitation of forest resources from local communities' members, its conflicting directives and weak laws lead to making charcoal production and trade unsuccessful. In return, people resort in making illegal production of charcoal and evade levies imposed on the related activities.

As such effective government support to these communities may help raise their standard of living while making charcoal production more acceptable by changing community perception of illegality of charcoal activity. This would in turn promote biomass energy sector and make the activity sustainable without compromising to negative environmental implications associated with unsustainable production of charcoal.

1.13 Conceptual Framework

This conceptual framework shows the relationship between the variables identified; the independent variables which directly affect the dependent variable. Unforeseen circumstances can occur which affect the dependent variable that is known as the intervening variable.

Independent variables consisted of four components; Wood harvesting which entails of harvesting methods practiced by the actors, where the wood is commonly harvested, and the stakeholders involved. Traditional earth kilns entail how they are structured/ constructed, the quality and quantity of charcoal that can be produced and the effects it has on the environment and people. Distribution of benefits along the value chain consist of which actors makes the most profits and how the pricing of the product on each level of the value chain is determined.

Dependent variable is charcoal production, with focus was on the quality and quantity of its production. Intervening variables in this study looked at government policies and climate. Government policies which are charcoal related due to underwhelming levels of implementation does affect charcoal production. In recent case with the charcoal ban in effect has affected the charcoal industry in the country, with government taking measures to ensure charcoal production is not taking place in the natural forests. The conceptual framework is depicted in Figure 1.1.

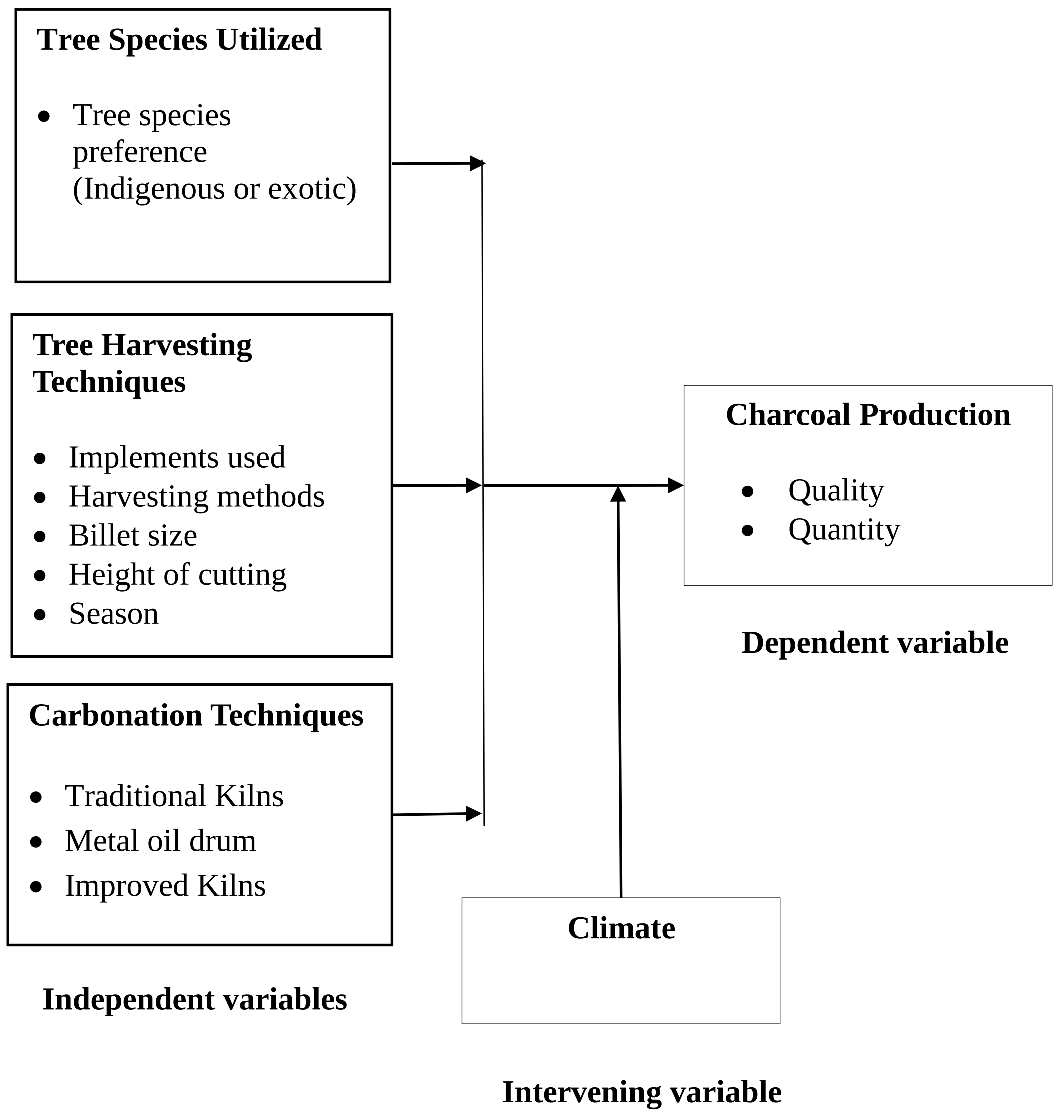

Figure 1.1: Conceptual framework showing the relationship between the factors influencing the charcoal production in Mau west Forest, Kericho County

CHAPTER TWO

LITURATURE REVIEW

2.1 Introduction

This chapter summarized studies from other authors who carried out their research in the same field of study. The specific areas covered here included the theoretical review and empirical review where studies related to harvesting methods, earth mounds kiln, tree species in relation to charcoal production were discussed and the pertinent gaps identified.

2.2 Charcoal Production

2.2.1 Charcoal Production in Sub Sahara Africa

Global demand for energy is projected to rise exponentially in the coming years, with population growth and lifestyle shifts in emerging economies putting ever greater pressure on existing grids for energy supply. This could be especially true for Africa, where economic growth can be directly related to energy demand: an increase in GDP of 1% is expected to entail an increase in energy output of 0.55%. In addition, Africa accounts for about 13 % of the world's population but as of 2001 consumed just 5.6 percent of global energy supply (UNESDA, 2004). As a result, African energy consumption per capita (about 41 % of the global average) is projected to increase with increasing trade, changing lifestyles, and developing infrastructure (UNESDA, 2004).

Due to its wide spread lack of access to modern energy sources such as kerosene, liquefied petroleum gas (LPG) and electricity (UNDP, 2009), Sub-Saharan Africa (SSA)–with the exception of South Africa, where coal is a major fuel–has the largest proportion of its population dependent on conventional biomass, mainly firewood and charcoal(IEA,2006,IEA, 2010).

SSA also depicts the highest regional wood energy consumption per capita in the world, with an average consumption of 0.69m3/year in 2011, compared with a global average of 0.27 m3/year (Liyama *et al*., 2014). An approximate 93 % of SSA households rely on wood energy to meet their daily cooking needs. Although firewood remains the preferred option in rural areas (Mwapamba *et al*., 2013), charcoal is particularly common in urban markets due to its higher energy content, easier storage and trans-port, and lower smoke output relative to firewood (Bailis, 2005, Liyama *et al*., 2014)

About 2.7 billion people worldwide depend on solid biomass resources for domestic operations and this number is only expected to decrease to 2.3 billion by 2030 (IEA 2015). By 2050, biomass is expected to comprise 30% of the global primary energy mix (IEA 2010), and 87% of global biomass intake is estimated to come from wood fuel (IEA 2009), one of the highest forest sector contributions (Arnold & Persson 2003).

The production of charcoal plays an important role in the economy of most sub-Saharan African countries. The value chain offers multiple jobs at every step of the chain. Although jobs are provided in the supply chain, a large amount of revenue is actually going to connectors-middlemen, transporters and wholesalers-with very little going to charcoal producers.

Charcoal production and its trade have a major contribution to the economy of the country. It creates jobs, rural income and government tax revenue, in addition to saving the foreign exchange of the country that would have been used to import such fuel (Mugo & Ong, 2006). Fuel wood and charcoal typically build significant workforce in the biomass energy sector. A survey carried out in Tanzania, Dar-Salaam, for example, suggested that the processing and trade of charcoal provided jobs for hundreds of thousands of locals. Of these, most were the poorest in the group who had lost any alternative livelihoods (Sepp, 2008).

Revenues in the charcoal value chain in Tanzania was unequally distributed according to World Bank (2009). The charcoal producer can earn as little as 20 per cent of the final charcoal retail price paid by the urban customer, while traders typically earn a slightly higher percentage. This can be due to several reasons: a) the supply of unskilled labor is large; b) independent producers are not organized and therefore cannot exercise any negotiating power; c) cartel or monopoly-market structures organize transport and large-wholesaling; d) retailers are again not organized and have no market influence. Producers and sellers are unlikely to be organized into community groups or cooperatives since many are working illegally.

Around 3 million people in Ghana have their livelihood source in the charcoal sector, with more than 50 percent of these individuals being women (Mombu, and Ohemeng, 2008). In Uganda, about 2,000,000 people have a permanent source of earnings from charcoal operations. It has also been found that households involved in the manufacture and trade of coal are likely to avoid dropping below the poverty line (Khundi et al., 2010). Cattle farming and charcoal production are the two economic activities from which rural people can get fast cash but farmers are not willing to sell cattle where charcoal is readily available, despite the two choices (Knoepfle, 2004).

The key point is that while there are few resources to get cash from, charcoal is the vulnerable target when it comes to fast and simple cash realization. It can therefore be argued that the production of charcoal is prevalent among the poor, since it provides very easy access to cash capital, rather than being the only choice to increase cash. In the Rwandan value chain, the wood production sector has been estimated at US$ 8.7 million, US$ 17.5 million in carbonization, US$ 19.7 million in transport and US$ 6.5 million in retail and distribution (Blodgett, 2011).

Minja claims, however, that unregulated tree cutting for charcoal production has largely contributed to the sad state of affairs, which is viewed as the simple way out of poverty. Whether unsustainable coal production may, in fact, be a route out of poverty remains in doubt. Despite this arguable connection, Khundi et al. (2010) found no evidence to indicate that the production of charcoal is the domain of the poorest households. On the contrary, poverty rates among charcoal producers appeared to be lower, and it was hypothesized that this is a direct result of their participation in the charcoal trade.

The literature indicates that while the charcoal market overall is lucrative due to the high demand and presence of a very robust distribution network (Müller, et al. 2011), not all players in the charcoal value chain are financially benefiting. The World Bank (2009) found that charcoal manufacturers, small-scale transporters, and retailers (who far outnumber stronger wholesalers and transporters) earn a very small share of the final market price. Charcoal manufacturers, who are the focus of the majority of the poverty-theory studies, are the supply chain segment with the goal of illegally obtaining the product and the segment with no capacity to invest in afforestation and reforestation.

2.2.2 Charcoal Production in Kenya

Like most sub-Saharan African countries, Kenya derives most of its energy from wood fuel and other forms of biomass energy (91%). Furthermore, as is common in developing countries, the residential sector is the largest energy consumer (73%)(Bailis, 2005). The charcoal of Kenya is produced almost entirely by manual laborers. Production is scattered across thousands of locations, primarily in the expansive forests and shrublands of the country, which make up more than two-thirds of Kenya's total land area. Together, rural and urban households accounted for more than 80 percent of coal consumption. The balance is accounted for by commercial, industrial, and institutional consumers, including restaurants, businesses, small-scale industries such as metal workers, and schools.

Since 2018, the production of charcoal on the entire national territory has been officially banned (Julius Chepkwony, 2019), as the charcoal industry is focused on a declining resource whose sustainable use seems difficult to enforce. Hence current production in Kenya is largely considered illegal. Yet development and consumption remain de facto a significant part of Kenyan society and the informal economy. Charcoal development affects Kenya's ecosystem either by felling trees from protected forests or as a by-product of land clearing for construction, farmland, or agricultural purposes. This leads to biodiversity loss, soil degradation, reduction of water catchment and increased greenhouse gas emissions (ESDA, 2005).

The charcoal sector in Kenya is very important not just for energy supply but also as a source of revenue and a potential for a substantial tax base, if properly controlled. The fact that its development and distribution take place with less work opportunities in rural areas decreases the rural-urban migration associated with employment-search. The charcoal chain has well-established systems of processing, transportation and trade, but continues to be hindered by the lack of a proper legal framework for the operations. This has perpetuated corruption and discrimination against operators (producers, hauliers and traders) denying them the chance to prosper and achieve their full economic potential.

Nevertheless, charcoal preference remains prevalent for various reasons: long-life storage and low-cost transport due to its smaller volume and weight (one third to one fifth of fuelwood); high heat content of around 7,000 kcal / g compared to 3,000 kcal / g of dry fuelwood and 1,000 kcal / g of green fuelwood (Ndegwa, 2016); can be obtained in small quantities, making it versatile and affordable; Similarly, charcoal-burning stoves are relatively inexpensive, making them more appealing to urban poor than other fuels available in urban markets like LPG and electricity. Kerosene, which is quite a substitute for charcoal fuel, is subject to market fluctuations (Bailis,2005).

2.2.3 Charcoal Quality in Kenya

As per a study conducted on implications of charcoal business to the environment (Absolom, 2014), charcoal can be produced from simple earth kilns to brick or metal kilns through a variety of methods. Earth kilns, masonry kilns and metal kilns are the three most common methods of charcoal production. Both in Kenya and in the rest of sub-Saharan Africa, the earth kiln is the most common method of making charcoal.

Earth kilns are of different types, but traditional earth kiln, improved earth kiln, and Casamance kiln are the most common. In order to increase production efficiency and reduce emissions of potentially harmful contaminants, improved charcoal processing technologies have been implemented. Nonetheless, due to limited knowledge, poor technological capability, and high investment costs, the use of these technologies remains very small.

A study conducted on charcoal production and how to enhance its sustainable production in Kenya, (Njenga et al., 2013) reiterated that, many see the charcoal industry as a natural resource and climate threat, and their fear is legitimate. More than 75% of the country's charcoal is generated unsustainably. Ironically, the charcoal industry could save the world it is now destroying if communities and private practitioners cultivate trees for charcoal and harvest trees sustainably by proper management plans. Through implementing short rotational agroforestry systems, there is potential for increasing tree cover and producing charcoal. The Kenya Forestry Research Institute (KEFRI), showed that a six-year-old *Acacia xanthophloea* tree produced charcoal with calorific value of 33kJ/g. The fixed carbon was 70 per cent, within the range of good quality charcoal, which is 50–95 per cent. Via government technical extension programs, the work of research and development organizations may help advise farmers on appropriate tree and shrub varieties, optimum tree management and rotation times, as suggested by stakeholders at a charcoal seminar at the World Agroforestry Center (ICRAF).

2.2.4 Charcoal Quantity

Researchers have suggested that charcoal is a poor man's enterprise. Mutimba (2005) found that despite the huge entrepreneurial potential, small scale charcoal producers in Tanzania and Kenya do not produce charcoal as some sort of business, but simply do it for survival. Likewise, Mugo and Poulstrup (2003) suggested that the lack of alternative forms of livelihood has forced many charcoal burners in Kenya to take up the trade on a subsistence basis.

According to a country wide report done by the ministry on environment in Kenya, the estimated number of bags produced annually based on the survey is 70,000,000 bags, translating to about 2,500,000 tonnes of charcoal being produce. This represents an increase of 53% from the figure of 1.6 million tonnes reported for 2005 (Mutimba and Barasa 2005). The figure is slightly lower than the figure of 3,632, 663.44 tonnes that was projected by Kamfor (MoE, 2002) for the same population (44 million) under the business as usual scenario, but higher than the projected figure of 2,070, 649.89 tonnes with the introduction of policy, legislative and institutional changes within the sector(Ministry of Environment, 2013).

Due to rapid urbanization and changing rural consumption patterns, charcoal use has increased at a rate that far exceeds overall population growth over the past two decades. Unfortunately, domestic energy surveys are rare, and data are not available to monitor the growth pattern in detail. The Beijer Institute conducted the first such survey in 1980 with funding from Netherlands and Swedish development organizations (O'Keefe, Raskin et al., 1984; Hosier, 1985). A second survey was completed in 1997 (Kituyi, Marufu et al., 2001) and a third survey was carried out more recently, in 2000, with the results published at the end of 2002 (Energy Ministry, 2002). The fourth survey was carried out by ESDA which was released in 2005 (ESDA, 2005). The fifth survey was done by the ministry of environment, released in 2013 (Gok, 2013). With such few national surveys, getting to know the trend with charcoal production is difficult.

As indigenous tree species are favoured for charcoal production have been selectively removed from the rangelands, transport distances have increased, and prices are consequently at record levels – now over KES 28/kg at wholesaling sites in Nairobi and up to KES 35/kg at retail4. On this basis the annual retail value of the industry is currently thought to be around KES 80 billion (USD 920 million) (Owen, 2013). This figure has increased from KSh 32 billion reported by ESDA (ESDA, 2005).

According to National charcoal survey conducted by ESDA 2005, Production from the government forest does exist. These kinds of producers are called sneak and snip producers. These are indiscriminate producers who illegally venture into government land (forests and game parks) and steal tree resources. This was observed in adjacent government forest areas such as districts bordering Mt. Kenya forest, Mt. Elgon forest, Kakamega forest, Mau forest, and some sections of Mombasa road. A recent aerial survey carried out in conjunction with the United Nations Environment Program (UNEP) by the East African Wildlife Society (EAWS) over the Aberdare-Mt Kenya forest revealed a disturbing number of charcoal kilns.

An important point to note is that most of these producers are also illegal loggers who harvest the timber for non-charcoal uses, using only the remains for charcoal. This type of unsustainable charcoal production is the most degrading kind.

2.3 Harvesting Methods

Wood fuel is one of the forest's major products. Approximately 60% of the world's total forest and external wood removals are used for energy purposes. While developed countries only use 30% of wood produced for energy purposes, developing countries use 80% for the same purpose (Energy Commission). Timber extraction for wood fuels accounts for 61% of the total removals of wood (Osei, 2015).

2.3.1 Wood Harvesting Methods

The charcoal value chain starts where the tree grows, and the wood is cut and ends with its consumption and includes all the economic activities undertaken between these stages. Many different stakeholders participate in the value chain; right from wood production, carbonization of the wood, packaging and transportation of the charcoal, retailing and distribution, and consumption. Wood production is the process of cutting down the trees into sizeable logs to be carbonized. This is the first stage in the CVC. These trees can be logged through selective logging as majority of the charcoal producers have preference of trees species. A case study on Charcoal production through selective logging in Mutumo District by Ndegwa., et al (2016), ascertain that charcoal production is mostly through selective logging of hardwood species which are preferred for their dense charcoal and high caloric value.

A comparative study on charcoal yield produced by traditional and improved kilns in Nyaruguru and Nyamagabe districts in southern province of Rwanda by Nahayo., et al (2013) mentioned the species of *Eucalyptus maidenii* as species of choice for this study. The wood was cut for three weeks and dried in solar energy before the carbonization operation begins; this is necessary to reduce the amount of water content in order to minimize the amount of heat energy wasted during the drying stage.

a)  ***b)*** 

Figure 2.XX: Live Trees Being Harvested for Charcoal Production

2.3.2 Stakeholders Involved in Wood Harvesting

The charcoal value Chain and improved cook stove sector analyses commissioned by SNV in December 2010 for Rwanda, shows that wood producers are the largest employed sector in the CVC, employing, at least to some extent, 300,000 people. These stakeholders, and most of the entrepreneurs and workers throughout the CVC, are almost exclusively individuals or small informal enterprises. The wood producers also play the main role in wood production. The producer may own and manage his/her forest, in the case of a private plantation, and have laborers to cut wood or do the cutting his or herself, depending on the size of the forest. Wood producers may also illegally cut wood, in the case of some sector and district plantations. The wood producer is required to request for a permit to cut wood. If the forest is less than 1 ha, the sector official can grant the permit. For cutting of a forest of greater than 1 ha, it is necessary for the District Official from NAFA to grant a permit for the cutting.

Wood for the production of charcoal in Kenya is produced by both legal and illegal means. The national charcoal survey found that most of the trees used in the production of charcoal came from the producer's own farm and from private land, including ranches converted to agriculture or cleared to pave the way for grazing. According to the study, illegal production of charcoal from protected government forests contributed about 13% of total production of charcoal (Ministry of Environment, 2013).

In order to realize sustainable wood for charcoal production there are three possible interventions which can be used namely: use of decentralized forest management approaches that embrace local stakeholders for sustainable natural forests, increased tree-plantations or woodlots and increased use of incentives of trees-outside forest by use of Agroforestry systems. Use of community-based forest management approaches provides best way in supplying increasing demands of wood for charcoal production. Community-based forest management model ensures involvement of the community in a sustainable management of natural forests and utilization of sustainable resources for commercial purposes (ESMAP, 2010).

The terms timber harvesting and timber logging are generally used synonymously in forest engineering. Timber harvesting encompasses all the activities undertaken to convert a standing tree into utilizable products delivered at the mill or other end user. Examples of timber products include poles, logs, chips and firewood. According to RCA (1992) timber harvesting precisely involves harvest planning, tree felling, debranching, cross cutting, extraction and site rehabilitation after harvest (Puentes-Rodriguez et al., 2017).

A timber harvesting operation is accomplished by making use of harvesting systems and harvesting methods. However, some literature uses harvesting systems and harvesting methods interchangeably. In this study, a distinction is made between harvesting systems and harvesting methods. “A harvesting system refers to tools, equipment and machines to harvest an area,” according to Pulkki (1997). Generally, manual, animal-motor-manual, semi-mechanical and mechanized harvesting systems exist in commercial tree harvesting and timber transport (Okoko et al., 2000).

Harvesting systems are selected based on environmental, technological and socio-economic feasibility in relation to site factors. According to Silayo *et al*. (2007), such factors as terrain, tree size, climatic conditions and skill of operators influence systems selection. In the Viphya forest plantations, common harvesting systems include manual and semi-mechanized (Bourque et al., 2009).

Pulkki (1997) defined harvesting methods as the assortments or form in which wood is delivered to the mill or end user. Common types of harvesting methods are cut-to-length (CTL), tree length (TL) and full-tree (FT). In each of these methods, manual, semi-mechanized or mechanized harvesting systems could be involved in tree felling, debranching, cross-cutting, topping and extraction phases (Adenaiji et al., 2015).

In semi-mechanized harvesting methods, trees are severed from their root systems, debranched, crosscut and topped using chainsaws. In mechanized methods, harvester processors and feller bunchers (mechanized systems) are quickly gaining ground in felling operations. Harvesters fell, debranch and cross-cut timber into desirable lengths while feller bunchers fell and bunch the trees (Dam, 2017).

Chainsaws are the most versatile tools for processing large diameter trees, and they are not limited by ground physical conditions such as slope as opposed to mechanized felling. However, felling direction remains a challenge to facilitate extraction (RCA, 1992). On the other hand, mechanized equipment is characterized by high initial costs making them inaccessible for small logging contractors. As such, the decision and location to crosscut or debranch a tree may vary depending upon the type of harvesting systems (tools, equipment machines) that are in place (Fuwape, 1996).

For instance, in a CTL method, the tree is felled, debranched and crosscut into short assortments at the stump area or at the landing. Short log assortments are extracted using forwarders or non-articulated trucks to the landing or mill. The method is particularly popular where small diameter logs and mechanized harvesting systems are present. However, manual CTL methods are used in the Viphya forest plantations among *in-situ* pit sawing contractors. Large diameter logs are processed infield using axes or chainsaws and rolled manually to the sawing deck for conversion into rough sawn timber (Fuwape & Akindele, 1997).

In tree length methods, felling, debranching and topping are carried out within the compartment where chainsaws and feller bunchers are ideal for converting trees into a TL. Cable, grapple and clam bunk skidders are the primary machines used in the transportation of tree lengths from stump area to the landing. This method is seldom used in harvesting pine but common in *Eucalyptus* (for transmission poles) on the Viphya forest plantations. Cable and grapple skidders are used for primary transport where cross-cutting of logs into required product specifications is carried out at the landing and mill (Kabisa et al., 2020).

The other method is full tree. Pulkki (1997) and Eggers *et al.* (2010) indicated that FT method involves extraction of wood (logs) with branches and tops from the stump area to the landing. Felled trees are mechanically or manually debranched at the roadside (landing). It is, therefore, clear from this method that huge volumes of slash accumulate at the landing area posing environmental challenges (e.g. fires). However, this method is widely used in harvesting pine timber on the Viphya forest plantations using semi mechanical systems. As the skidders drag (extract) felled trees, most of the branches get removed on the way due to ground friction. It is envisaged that chainsaw costs associated with debranching are viably reduced by the time the felled tree is processed at the roadside landing (Kalaba et al., 2013). In a FT method, all types of skidders are applicable for extraction operations to the landing. However, absence of self-loading mechanisms makes cable skidders less competitive to grapple skidders. In fact, Kluender *et al*. (1997) found that grapple skidders had shorter extraction cycle times than cable skidders on similar harvesting sites.

Manavakun (2014) addressed the timber harvesting potential in Thailand including: average productivity, identifying ineffective work phases, and how work performance can be improved. Therefore, the study was conducted to analse existing timber harvesting systems as a whole and compare alternatives, and to explore improvements in forest harvesting systems through work study, working postures analysis, and simulation. This study confirmed that motor-manual operations have rather low production rates compared to intermediate and fully mechanized harvesting techniques, which are applied in other parts of the world. The most unproductive work phase is cross-cutting, and further research should pay attention to this work phase. According to the working postures analyses, the most problematic working postures found for manual tasks included stacking, delimbing, and loading. Simulation findings suggested that reorganization of job sequences is one major possibility for improving productivity.

Log length and tree size also displayed a significant effect on overall productivity. The study was conducted in *Pinus kesiya* stands at Kalungulu and Champhoyo forest stations of the Viphya forest plantations. A work study approach was followed to capture harvesting time and volume data. Stepwise multiple regressions were used to develop felling time models for a chainsaw over tree size, inter-tree distance, slope, ground condition, brush density, and ground roughness; and skidding time models over distance, slope, ground condition, ground roughness and volume skidded per cycle for a grapple skidder. Models were statistically validated. Secondary work study data for semi-mechanized systems were simulated for mechanized productivity based on local site factors.

The study had shown that diameter at breast height and inter-tree distance were important factors that best explained felling time prediction models in *Pinus kesiya* stands on the Viphya forest plantations. Similarly, distance from stump to the roadside landing was the most important factor in addition to volume load, slope and ground conditions that determined grapple skidding time. Mechanized systems appear to be more advantageous than semi-mechanized systems. The former is associated with lower operating costs and inventories with relatively high production rates. Therefore, mechanized systems could help to optimize timber harvesting productivity on the Viphya. Ghaffariyan and Brown (2013) did a study on selecting the efficient harvesting method using multiple-criteria analysis: A case study in south-west

Western Australia. Four harvesting methods were compared in Western Australian Eucalypt plantations including cut-to-length (CTL), in-field chipping using a delimbing and debarking flail integrated with the chipper (IFC-DDC), in-field chipping using a chipper with a separate flail machine for delimbing and debarking (IFC-F/C) and whole tree to roadside (WTR). The decision criteriaa consisted of total operating cost (from stand to mill gate), yield per ha, harvesting residues, fuel consumption and bark content of the chips. The Promethee method was used to evaluate the alternatives using Decision Lab software. Based on the results, the IFC-DCC was the best harvest method while WTR method was the worst harvesting alternative in the case study area. IFC-DCC method resulted in the lowest operating cost and the highest recovered yield per ha compared to the other harvesting methods.

2.4 Carbonation Methods

Charcoal can be produced through various methods such as simple earth kilns, brick kilns and other ways in which the process essentially charcoal is produced under a process called pyrolysis which involves breaking down of the chemical structure of wood under high temperature in the absence of air; after the process is complete charcoal is removed from the kilns (Adam, 2009). According to Hofstad (1997) around two thirds of energy is lost during the process and severity of the problem depends on the techniques of the producer such as using traditional methods or improved methods.

2.4.1 Earth Mound Kiln

There are several techniques which uses the earth mound process to produce charcoal in Kenya and they do vary in their efficiency. The most commonly used technique is traditional earth kiln. The kilns include wood that is neatly and tightly stacked on the ground and over the stack is placed a layer of green material including grass. The pile is then completely covered with sufficiently thick soil to prevent air from entering the wood. Until the pile begins to burn and the area is covered, the ignition area is exposed to wind. The results are best when closely monitoring the charring process to ensure controlled air.

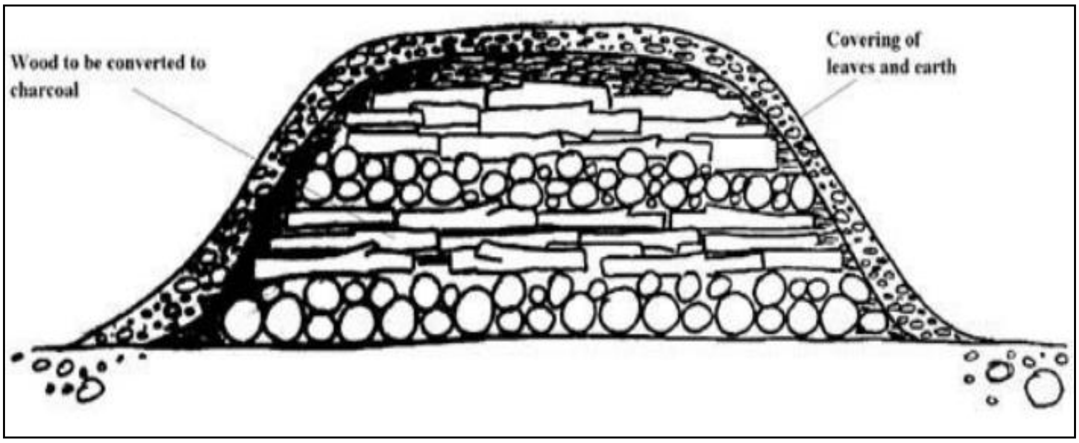

Figure 2.1: Structure of the earth mound kiln
Source : (Kalenda, Ngatia, NG'oriareng, Oscar, & Oduor, 2015)

The Kiln is easy to build and the material needed are not expensive. The other advantage is that it can be built where the materials are found, this reduces transportation and labour costs. The method has undergone many changes over the years and the process has become efficient yielding up to 33 % recovery rate (The Marakwet Kilns-Senelwa). However, control of the carbonization process is not always easy in most cases this results in low-grade charcoal, contaminated with soil crumbs and low recovery rates of up to 15% (Kalenda et al., 2015).

A study on charcoal value chain done in Kenya, MENWR (2013), ascertain that over 90% of charcoal in Sub- Saharan Africa including Kenya is produced using traditional earth-mound (Figure 3.2). Kilns with very low wood to charcoal conversion efficiencies ranging between 10% and 15%. Sustainable production systems and appropriate modern technologies are lacking. Production is commonly carried out by small, economically weak and unorganized individuals or groups using wood from unsustainable sources. In Kenya, wood-to-charcoal conversion efficiency rates range between 10-15 % with only a few cases achieving rates above 20%.

Figure 1.2: Traditional earth mound kiln in one of the study areas.

This type of kiln has been blamed for huge losses of wood with reported efficiencies of between 9% and 15% in different countries (Mugo and Ong, 2006). There are other kilns with higher efficiencies higher than 15% but these remain out of reach for most charcoal makers. These ranges from stationery brick kilns, metal kilns and concrete kilns but these have lower adoption in developing countries due to; high investment costs, lack of portability, lack of construction and operation skill among the charcoal makers (Kituyi, 2001) and free procurement of wood from government and communal trust land (Sepp, 2008). The informal and sometimes illegal nature of the charcoal sector in some countries also plays a part by putting off potential investors who can afford the technologies.

A study on efficiency of charcoal production in Congo, Schure, et al. (2019), focused on improving the efficiency of carbonisation as one contribution to more sustainable charcoal value chains. While the efficiency of wood- to-charcoal conversion is often considered a technical matter of kiln performance, this study aims to shed light on the role of the enabling institutional context and the capacities of the players involved.

Traditional charcoal producing methods were virtually the only methods used until the beginning of the twentieth century. Wood was put in dug-out earth pits, lit and covered with earth. The combustion of part of the wood produced enough heat to carbonize the remainder. This method allowed a bit of more control over combustion and carbonization than the pit method. Both techniques persist to this day in many developing countries, mainly because they are cheap. However, they often produce very low yields (typically 1 kg of charcoal from 8 to 12 kg or more of wood), inconsistent quality (because it is difficult to maintain uniform carbonization) and environmental pollution from the release of tars and poisonous gases (Abdallah and Monela, 2012).

In the 1970s and 1980s, efforts were made to improve traditional charcoal making by equipping earth kilns with chimneys made from oil drums (Casamance kilns) and by introducing small-scale steel or brick kilns. Currently, in Tanzania there are two known improved kiln efficiency projects, the Half Orange Brick Kiln (HOBK) and the Improved Earth Mound Kiln (IEMK). The average carbonization efficiency of these improved technologies is estimated to be in between 27–35% which seem to be more advanced compared to the kilns EPK and EMK. Therefore, use of the Improved Earth Mound Kiln (IEMK) with better kiln management could be a better option than EPK and HOBK. The IEMK is based on the traditional earth mound kiln but modified by limiting air supply thereby controlling inlet air and limiting the exhaust air to a single chimney.

According to Bailis (2013) the EMK is the common method of making charcoal Tanzania with conversion efficiency ranging 10 and 20%. Chaposa (2002) reported that in Tanzania $1m^3$ of wood has a yield of 2.7 bags meaning that with a kiln with average efficiency of 19%, 18 trees of 32cm at breast height can produce 56 kg of charcoal. Factors influencing kiln efficiency variation included moisture content of the wood involved in kiln preparation and its weight meaning that tree species used significantly affects kiln efficiency (Hofstad, 1997). Other factors which affect efficiency according to Ishengoma and Nagoda (1991) include lack of proper control during carbonization process as a result of complete combustion of some of the wood; CHAPOSA (2002) reported that the is problem is common especially for seasonal charcoal producers who are not well experienced.

Khristova and Khalifa (1993) did a study on carbonization of some fast-growing species in Sudan. Four wood species, indigenous *Acacia seyal* (talh) and exotic fast-growing *Conocarpus lancifolius* (damas), *Eucalyptus microthera* (kafur) and Prosopis chilenis (mesquite) grown in Sudan were assessed and compared as raw materials for charcoal making. The effects of production method (traditional earth mound and improved metal kiln) and the physical and chemical properties of the wood and bark on the yield and quality of charcoal produced were assessed. Regression analyses of wood properties and heat value indicated high negative correlations of the wood heat value with holocellulose and ash, and high positive correlations with wood density, lignin, and alcohol-benzene and hot water solubles. Carbonization with the Tropical Products Institute, metal kiln produced higher yields (33%) than the traditional earth mound (27%), although the difference in energy transformation yields was found to be insignificant both between appliances and species. Charcoal produced by the earth mound had a slightly higher density and was more resistant to shatter, but no significant differences were recorded with respect to the water boiling test or the gross heat value. The exotic species studied gave equal or better charcoal, in terms of yield and quality, compared with traditionally preferred *Acacia seyal* (talh).

Wood charcoal, especially made from hardwoods such as oak, hornbeam, beech, olive and citrus, is known best and preferred as the primary fuel in most of Turkey for grilling and barbecue. The use and demand of wood charcoal has grown in Turkey and it is still widely produced by migrant charcoal producers with traditional methods by using earth mound kilns. Menemencioglu (2013) did a study on traditional wood charcoal production labor in Turkish forestry. Data collected from 44 kilns at two sites resulted with the mean kiln efficiency of 19% ranging from 17-22% (1 kg of charcoal from 5 to 6 kg of wood) which were constructed by 23 adults, using 1350 tons oak wood and having 255 tons of charcoal equivalent to approximately 10000 sacks of charcoal for about 7 months period. All 44 active kilns observed in the charcoal production sites during the study time were traditional earth kilns, ranging in size from 25 to 45 m.

Syampungani and Chisanga (2011) investigated the influence of stump diameter and stump height on the coppice effectiveness in relation to interspecific variation. The study showed that coppice effectiveness results varied among the key tree species with *Brachystegia longifolia* and *Isoberlinia angolensis* having the highest number of coppice shoots (9.8 ± 2.6) and 7.5 ± 1.6) and the least being *Julbernadia paniculata* (4.2 ± 1.3). High coppice effectiveness indicates a greater recruitment potential for Miombo species. The study revealed that the coppicing ability of miombo trees is species dependent. The results therefore suggest that management of miombo species should be species specific rather than holistic. The research has also provided a model for planning when cutting of the Miombo species for charcoal production in terms of the diameter classes to optimize on coppice ability of harvests.

Adeniji, Zacchaeus, Ojo and Adedeji (2015) determine the demographic characteristics of the producers, examine and explore charcoal production methods and processes, identify the tree species used in charcoal production and explore their desirable qualities, as well as examining the sustainable charcoal production in the study area. Purposive sampling technique was employed in the study. The results of the study revealed that earth mound kiln (65%) and earth pit kiln (35%) are the two methods of charcoal production employed by the producers in the study area. *Prosopis Africana* (73%) is the most preferred tree species used by charcoal producers in the study area for charcoal production. The study revealed that commercial charcoal production was gradually becoming one of the major sources of sustenance and currently plays a major role in promoting entrepreneurial development in Borgu L.G.A of Niger State with earth mound kiln method (65%) mostly employed.

Kimaryo and Ngereza (1989) did a preliminary field survey of earth kilns in nine villages in Tanzania. Only one design of the traditional earth kiln was found commonly adopted in the surveyed villages. The effect of the basic design on charcoal yield and production cost was evaluated for comparison among villages. The charcoal recovery percentages from single kiln-charges in the villages are unexpectedly quite high, ranging from 17 to 37 per cent. The yield variations between villages are significant due to lack of field control of certain factors of production: tree species, wood density, billet moisture content, kiln capacity, operating skills and prevailing weather conditions. The unit production costs show no significant differences between village charges.

Schenkel, Bertaux, Vanwijnbserghe and Carre (1998) analyzed the different kinds of mound kiln carbonization methods used throughout the world and include a brief description of their construction and operational aspects. The study also analyzed various indicators and assess the quantitative and qualitative efficiency of a carbonization: mass yield, energy yield, balanced mass yield. Finally, the study compared the mound kiln carbonization technique with other improved carbonization methods. The comparison showed that the mound kiln carbonization method could be as efficient as improved methods and is characterized by mass yields ranging from 20 to 30% dry basis, and by fixed carbon contents above 75% dry basis. The key factor of the mound kiln carbonization method is the know-how of the charcoal maker.

Experimental charcoal burnings were conducted at Kileo Forest Reserve, Mwanga District, to measure the technical and economical performances of five earth kiln models. The results show quite significant variations in yields of charcoal between and within kiln designs. The recoveries between kiln designs range from 15 to 31 per cent. The unit production costs also differ quite significantly between the kiln designs tested, ranging from Tsh.1 per kg. (Tsh.39 per bag) to Tsh.3 per kg. (Tsh.108 per bag). The results obtained at Kileo indicate that the Senegalese Casamance earth kiln is the most technically and economically efficient design, followed by the metal channel kiln, an improved version of the basic earth kiln. The adoption of either of these two designs by the rural charcoal producers may greatly improve the present traditional method of charcoal production in the country.

Mopoung and Udeye (2015) did a study on wood charcoal and wood vinegar production from mango tree wood by using 3m^3 carbonization dome kiln. The charcoal and wood vinegar yield were measured. The calorific value, proximate composition, hardness, density, combustion calorific value, emission test, burning time and thermal efficiency of mango wood charcoal were evaluated. Economic of charcoal production was also analysis. The results showed that a 3 m^3 dome kiln needs 8 days for carbonization and 15 days for cooling with carbonization temperature of 450-550ºC. The charcoal and raw wood vinegar yield from capacity mango wood per kiln about 1500 kg/batch, are 26.49 1.55%wt/wt and 7.26 1.03%wt/wt, respectively. The mango wood charcoal has 7.57 dried wt%, 12.62 dried wt%, 79.8 dried wt%, 0.32 g/cm^3, 5252.88 cal/g, 12.95 0,00 kg, 0.79 0.04 kg/cm,79.77 µg/m^3, 41.83 ppm/s, 1924 ppm, 69 min and 16.40 0.00% of ash content, volatile matter, fixed carbon content, density, calorific value, hardness, ultimate strength, dust emission, average CO emission rate, total CO emission, burning time and thermal efficiency, respectively. The parameters of economic of mango wood charcoal production from 3 m^3 dome kiln are US$166 of kiln construction, US$90 of charcoal production operation, US$430 of reduce charcoal expenditure. The revenue from charcoal and vinegar sales is about US$7800/year/kiln. It is also reduced the greenhouse gas emission about 0.07 kg/kg mango wood.

2.4.2 Earth Mound Technique of Charcoal production in Western Mau Forest

The charcoal producers in western Mau forest use the traditional/earth mound technique of charcoal production. Charcoal is produced through a series of traditional methods and processes. The following processes was outlined by a commercial charcoal producer, as follows:

Commercial charcoal production process often commences with the selection of well-endowed trees location by the charcoal producer. The identified trees are then cut or harvested over a period of time for free. Some of the selected woodlands are family owned or communal lands where acquisition of permits is not often necessary.

Secondly, the cut wood (usually about 1m long) are sorted by diameter and stacked next to the burning site, as indicated in Figure 2.XX. The wood is then stacked into a dug-out earth pit or heap on a relatively flat plain up to a reasonable height and covered with a layer of grass/leaves and soil. Thus, the logs are piled on a relatively flat area of land with fresh leaves and grasses well covered over the logs. A heap of soil is then gently used to cover the entire heap leaving two very small openings for fire to be lit and smoke exit respectively. As indicated in several amounts of top soil and shrubs are needed to cover a single heap.

Finally, the fire is then lit from the opening. After the entire woods/logs catch fire the hole is sealed with small sticks and grasses. The process is then closely monitored both day and night for about 10-15 days, depending on the size and moisture content of the wood during carbonizing. Gradually the logs burn into the required charcoal.
During the process, a series of vents are created in each earth mound. This is done to allow proper ventilation and continued burning for up to a week or two depending on the size of the woods and the heap. If the earth kiln is not vented properly, it can either smother the fire before carbonization takes place or burn too hot, causing over burning, leaving only a pile of ashes. The process of carbonizing is completed when it stops smoking and cools. At this point, the charcoal worker begins raking and separating the dirt and debris from the newly formed charcoal. Between two and four days are spent in this process, depending on the size of the labor available. The charcoal is then collected into bags and sold either to charcoal merchants or individually along the roadside".

Figure 2. X: Sorted Woods for Charcoal Production

Figure 2.X: Earth mount method of charcoal production being used in the Mau West Forest

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Figure 2.XX: Earth mount method of charcoal production being used in Mau West Forest

Figure 2.XX: Finished Products (Charcoal)

The earth mound method of charcoal production inflicts damage to the vegetation. As observed from major charcoal producing sites in the study area, this process has several weaknesses. These weaknesses contribute immensely to the degradation of the natural environment. The method could trigger fires through the vents and other openings. The fires when not controlled or are mishandled they can destroy large portions of vegetation. Additionally, the method is inefficient as it encourages a lot of resource waste

2.4.3 Metal (Steel) Kiln

The kiln consists of two interlocking cylindrical sections and a conical cover. The cover is provided with four equally spaced steam release ports, which may be closed off with plugs as required. The kiln is supported on eight air inlet/outlet channels, arranged radically around the base. During charring, four smoke stacks are fitted onto alternate air channels (FAO, 1987). The steel kiln is a proven commercial method making charcoal in the developed world. In the developing world the problem is to overcome the high initial and repair cost (Booth, 1983).

Figure 2.4 Metal (steel) Kiln

2.4.4 Oil Drum Kiln

Charcoal can be produced in kilns manufactured from standard 45 gallon oil drums. This method has been operated successfully using fast burning raw materials such as coconut palm timber, coconut shells and scrub wood. However, when operated with dense hardwoods, complete carbonization is difficult to achieve and the resulting charcoal is likely to have a high volatile content. Even with low density materials the volatile content of the charcoal produced is somewhat high, although this is not a major disadvantage for a local domestic fuel. If the charcoal is to be produced for export, however, the use of proper metal kilns will enable the high quality demanded by the trade to be achieved. Compared with traditional methods of production the conversion efficiency obtained in oil drum kilns is comparatively high with reported yields of up to 23% on dry-basis (FAO, 1987).

Figure 2.XX: Oil drum kiln

Figure 2.XX: Charcoal producers burning charcoal in small scale in Mau West Forest

Plate 4. 1: Men and women engaging in Charcoal production activities in Mau West Forest in Kericho County

Figure 2. xxx: Charcoal production using traditional kiln and drum kiln

2.5 Tree Species Utilized

Bourque, Buchanan and Hassan (2018) did an analysis of habitat suitability and charcoal-yielding characteristics of five exotic tree species intended for bioenergy production in Jamaica, the study provided a detailed scientific analysis of fuel wood growth and yield characteristics, as well as fuel wood-burning and charcoal-yielding characteristics for plants grown in a model fuel wood project on the southwest coast of Jamaica. Mass production of charcoal was considered feasible with two of the five fuelwood species considered, namely *Acacia. auriculiformis* and *Leucaena leucocephala.* Both species had high charcoal yields (>20 Mg ha^{-1}), comparatively good charcoal-to-dry weight conversion ratios (>20%), high heating value (>14.4 MJ kg^{-1}), and an abundance of suitable planting sites across the island. *Senna siamea* had a greater number of planting sites identified, but its heating potential (14.2 MJ kg^{-1}) and charcoal yield (14%) were the lowest among the five species evaluated.

Claire, Andrew and Rovd (2017) in their study on floristic composition, species diversity and carbon storage in charcoal and agriculture fallows and management implications in Miombo woodlands of Zambia, provided an integrated understanding of aboveground (AG) C storage, structural and floristic composition in charcoal and agriculture fallows in Miombo woodland systems of Zambia. The study presented the findings of ecological surveys; measuring tree diameters and assessing species composition on twenty-four 0.25 ha plots in undisturbed woodlands, and 58 plots re-growing after agriculture (5–58 years) and charcoal production (5–44 years). Undisturbed Miombo stored 39.6 Mg C ha^{-1} AG, while after clearance, C stocks accumulated at 0.98 and 1.42 Mg C ha^{-1} $year^{-1}$ in agriculture and charcoal fallows respectively. There were no significant differences in C stocks between woodlands and ⩾20-year-old fallows, implying that in terms of AG C storage, woodlands sufficiently recover after 20 years. Stem densities were significantly higher in charcoal than agriculture fallows, but the difference decreased with fallow age. Importance values (IVI) of tree species show low presence of less fire-resistant tree species such as *Uapaca kirkiana* in the initial regrowth of post-agriculture fallows.

Fuwape (1996) determined the effects of carbonization temperature on charcoal from some tropical trees, three short-rotation tree species: *Gliricidia sepium*, *Leucaenea leucocephala* and *Gmelina arborea* were converted to charcoal by a pyrolytic process. The effects of final carbonisation temperature on the yield, heating value and proximate analysis of charcoal from the tree species were determined. *Gliricidia sepium* gave the highest charcoal yield of 51.6% with a gross heating value of 31.45 MJ/kg at 300°C final carbonisation temperature. There was no significant difference in the charcoal yield of *Gmelina arborea* and *Leucaena leucocephala* at 5% level of testing. The charcoal yield decreased with an increase in carbonisation temperature. The percentage volatiles in charcoal decreased with an increase in temperature, while there was an increase in the percentage fixed carbon. The high cost of conventional fossil fuels has resulted in a rise in the demand for charcoal in developing countries. There has been a problem of wood scarcity and indigenous tree species are being replaced with the fast-growing, short-rotation species.

Fuwape and Akindele (1997) analyzed biomass yield and energy value of some fast-growing multipurpose trees in Nigeria. The above-ground biomass yield of seven-year-old trees of *Gliricidia sepium*, *Gmelina arborea* and *Leucaena leucocephala* grown for fuel production were assessed. The combustion properties of the fuelwood and charcoal produced from the trees (moisture content, density, percentage fixed carbon, volatile matter, micro-elemental composition and heat of combustion) were determined. There were significant differences in the above-ground biomass and the charcoal yield from the various species. The stand biomass was 37.4 t/ha for *Gliricidia sepium*, 85.6 t/ha for *Gmelina arborea* and 46.2 t/ha for *Leucaena leucocephala*. The charcoal yield (range 25–42%) was highest in *Leucaena leucocephala*. The average heat of combustion of charcoal, 33.25 MJ/kg, was higher than that of wood, 21.6 MJ/kg. *Gmelina arborea* gave the greatest energy yield per hectare due to its high stand biomass.

Syampungani and Chisanga (2011) investigated the influence of stump diameter and stump height on the coppice effectiveness in relation to interspecific variation. The overall objective was to provide an understanding of the coppicing ability of the selected key miombo species in order to provide a basis for sustainable management of the species. A total of 102 stumps were observed. Coppice effectiveness results varied among the key tree species with *Brachystegia longifolia* and *Isoberlinia angolensis* having the highest number of coppice shoots (9.8 ± 2.6) and 7.5 ± 1.6) and the least being *Julbernadia paniculata* (4.2 ± 1.3). High coppice effectiveness indicates a greater recruitment potential for miombo species. The study has revealed that the coppicing ability of miombo trees is species dependent. The results therefore suggest that management of miombo species should be species specific rather than holistic. The research has also provided a model for planning when cutting of the aforementioned miombo species for charcoal production in terms of the diameter classes that provide high coppice effectiveness.

Silva, Numazawa, Araujo, Nagaishi and Galvão (2007) evaluated the main properties of the charcoal from *Manilkara amazonica* (maçaranduba), *Lecythis pisonis* (sapucaia) and *Piptadenia suaveolens* (timborana), carbonized in 7 and 10 days. The charcoal was produced from residues of timbers from sawmill of Cikel Brasil Verde S. A., in Rio Capim estate, Paragominas, PA. A series of 30 kilns was used, being 10 for each species, of which 5 kilns used a 7-day carbonization process and 5 kilns 10 days. After the carbonization, samples of the charcoal produced were collected for studying gravimetric yield and physical, chemical and mechanical properties. The main results were: gravimetrical yield of the charcoal varied from 21.47 to 29.59 % (humid base); the bulk medium density varied from 178.51 to 231.14 $kg.m^{-3}$; apparent medium density from 0.38 to 0.53 $g.cm^{-3}$; calorific power from 23451 to 28830 $kj.kg^{-1}$; volatile materials content from 23.94 to 31.47 %; ashes from 0.7 to 2.5 %; fixed carbon from 68.29 to 74.49 %; and the friableness varied from 12 to 32.6 %. It was noted that species is the main factor that influences the properties of the charcoal. It was not possible to say which species produced the best charcoal, from the property's analyses, because all the three species present some good characteristics, but these are always accompanied by other inadequate characteristics.

Pluchon et al., (2015) studied the influence of species identity and charring conditions on fire-derived charcoal traits. The study experimentally produced charcoal from three common boreal tree species under six charring conditions representing those encountered during boreal fires and then analyzed their structural and chemical traits. The study found that species identity affected charcoal traits more than did charring conditions. Among the structural traits, density and micro porosity varied among tree species, and density decreased with increasing temperature. Among the chemical traits, electrical conductivity, total nitrogen (N) and phosphorus (P) contents, and phosphate concentration differed among species, whereas pH, total N content, and ammonium concentration responded to charring conditions. No traits except nitrate concentration responded to the interactive effect of species identity and charring condition. The results revealed that traits of charcoal, and potentially its ecological functions, are driven by a combination of fire behavior and tree species identity; such information is relevant for understanding ecological consequences of altered fire regimes due to the changing climate and to forest management.

In Riyadh, Saudi Arabia, El-Juhany, Aref and Megahed (2003) did a study on properties of charcoal produced from some endemic and exotic acacia species grown in Riyadh. Production and properties of charcoal from four years old *Acacia assak*, *A. negrii*, *A. seyal, A. karroo*, *A. ampliceps, A. stenophylla* and *A. salicina* grown in the Experiments and Research Station, College of Agriculture, King Saud University, Riyadh, Saudi Arabia were studied. The first three species are indigenous while the others are exotic. 21 trees were felled and disks of 20 cm each from their stem were cut and shipped to the Wood Testing Laboratory at the Faculty of Agriculture, Alexandria University, Egypt. Specific gravity, charcoal yield and gross heat of combustion of the wood of these species were determined. Wood samples were charcoaled then the physical (apparent density, gross heat of combustion) and chemical properties (moisture, volatile, ash and fixed carbon content) of the produced charcoal produced were determined. *A. amplecips*, *A. negrii* and *A. asak* showed quality charcoal in terms of high gross heat of combustion and fixed carbon content with low moisture and ash content comparing with the other acacia species under investigation.

Medeiros Neto, Oliveira and Paes (2014) aimed to relate the characteristics of wood and charcoal of *Poincianella pyramidalis* and *Handroanthus impetiginosus* species. To this end, five trees of each species were felled, and parts of 30 cm in length were removed at 0 (base), 25, 50, 75 and 100% of the commercial height of the trees. This material was used for determination of the characteristics of wood and charcoal. *P. pyramidalis* produced greater yield of charcoal compared with *H. impetiginosus*; however, the wood of the latter species presented better characteristics for energy purposes. The two species showed different relations between anatomical, physicochemical and energy characteristics. The knowledge about the disparity between the relations of the wood characteristics enables its most adequate use for energy purposes.

In Ethiopia, Alemu (1997) studied wood fuel carbonization and charcoal characterization of six agroforestry tree species of Ethiopia, namely, *Acacia abyssinica*, *Acacia seyal*, *Albizia gumifera*, *Croton macrostachys*, *Grevillea robusta and Millettia ferruginea*. Wood charcoal was produced using partible, cylindrical, "mini" steel kiln. Physico-chemical and thermal properties of wood fuel and charcoal and carbonization productivity were analysed. The important analytical values were proximate analysis, calorific value, specific gravity, volumetric density and moisture content on wet basis. Carbonizations productivity (both energy and weight basis) was also determined. Significant differences in observed values were tested, analysis of variance and mean values were compared by Duncan's Multiple Range Test. Linear regression models for correlated properties were also examined. The differences obtained in proximate analysis, thermal and physical properties of wood fuel and charcoal between species were significant It was also observed that the conversion of wood into charcoal resulted in considerable change in volatile matter and fixed carbon percentage, decreasing and increasing respectively. The volatile matter, ash and fixed carbon contents of wood were 74.62 plus or minus 0.56 percent, 1.86 plus or minus 0.33 percent and 21.22 plus or minus 0.16 percent respectively. In contrast charcoal has 21.15 plus or minus 0.33 percent volatile matter, 3.25 plus or minus 0.44 percent.

Okello, O'Connor and Young (2001) did a study on growth, biomass estimates, and charcoal production of *Acacia drepanolobium* in Laikipia, Kenya. Suitability of *A. drepanolobium* for sustained charcoal yield in Laikipia, Kenya, was evaluated by developing predictive equations for standing biomass and charcoal production, and by undertaking a chrono-sequence analysis of its regrowth. Woody biomass was strongly related to stem diameter (Y=3.77 x+1.17, R^2=0.96, P<0.001). Mean charcoal production from earthen kilns was 2.83 Mg ha^{-1}. Height and stem diameter in coppicing stands increased at a mean rate of 28.6 cm year^{-1} and 0.7 cm year^{-1} respectively. Biomass in coppicing stands accumulated at a mean rate of 1.3 Mg ha^{-1} year^{-1} in a 14-year period, yielding dry biomass of 18.26 Mg ha^{-1} useable wood that can produce a minimum of 3.0 Mg ha^{-1} of charcoal. The study recommended that *A. drepanolobium* can be harvested for sustainable charcoal yield over a 14-year cycle. Production should be commercialized using modern kilns to improve efficiency and maximize yields.

2.5.1 Perception of Tree Species

In many sub-Saharan African countries, forests were exploited for the production of charcoal mainly by selective logging of hardwood species preferred for their dense charcoal and high caloric value. Well-planned selective logging, particularly of large canopy trees, improves the penetration of light into understory vegetation, stimulating natural processes of regeneration. However, selective logging targeting specific species has the potential to change the composition and physiognomy of the forests substantially and may have unwanted ecological consequences (Ndegwa, Nehren, Grüninger, Iiyama, & Anhuf, 2016).

According to a study by Ndegwa, et al. (2016), on Charcoal production through selective logging leads to degradation of dry woodlands, concluded that the production of charcoal by selective logging results in dry woodland degradation. Degradation is manifested by decreasing the density and basal area of preferred tree species. This study sheds light on the degrading impact of selective harvesting for charcoal production on dry woodlands with these findings, an issue that has generally divided views among researchers.

According to a survey conducted by the ministry of environment and forestry (2018), the indigenous forests are over-exploited by selective logging of important timber trees, which has greatly reduced the canopy cover, modified the forest composition, and undermined the regenerative capacity of the forests.

While all wood species may be carbonized to charcoal, charcoal quality varies from species to species and depends on the carbonization method. *Casuarina equisetifolia, Acacia mearnsii*, *Acacia polyacantha* and *Acacia xanthophloea* and other species of *Acacia* and *Combretum* are among the species reported to be producing high-quality charcoal (Ministry of Environment, 2013)

The study done by ESDA (2005), revealed that most (70%) of the charcoal traders preferred charcoal made from specific tree species, particularly the juliflora species Acacia and Prosopis. This is close to the results of Njenga et al., 2013; KFS, 2013; Njenga, 2013; Mugo et al., 2007; and a report by Melaku and Zenebe (2014) conducted in Ethiopia. It is also very similar to findings from Njenga (2013) who reported that charcoal producers in Kenya, Acacia tortilis, A are targeted while closed to 100 tree species. A.senegal, nilotica, A. Mellifera, and A. Cantha and A. The most favored ones were xanthophloea.

A study conducted in Tanzania revealed that, although all wood species can be carbonised to charcoal, charcoal quality varies from specie to specie and depends on the carbonization method (KFS, 2013). Large tree species (> 20 cm diameter) with high caloric values are preferred because of the large amount of dense and hard coal they contain (Monela et al., 1993). *Boehmii bachystegia, B. Bussei, Comretum sp, Bauhhinia sp, Acacia nilotica, Fluegea virosa and Swartizia madagacariencis*. Some of the species reported to be producing high quality coal (Msemwa, 2007).

Some of these are species from the Miombo forest. Tree species choice is based on the plant property to produce charcoal with a high recovery rate, a high calorific value that attracts buyers and therefore more profits to charcoal dealers because lighter charcoal with low calorific value has the problem of easily crumbling into small pieces or fines during transportation and thus decreasing market value (Zahabu, 2001).

2.6 Value Chain Concept

In the 1980s Michael Porter used the idea of value chain. He identified the value chain as the various actions that were carried out in the chain, in specific links. The value chain is a whole series of activities which at every phase generate and construct value. The overall profit the company produces is the gross amount of the value built up all over the company (Porter, 1980). Focusing on the value-creating activities will offer other benefits to the organization. Of starters, the opportunity to demand higher sales, lower production costs, improved public identity, quicker reaction to risks or opportunities.

Porter describes the value chain as including key operations and actions that sustain them. Key tasks include incoming storage (getting the products in to add value by storing it), operations (which are both production processes), outbound (which includes shipment to the points of sale), promotion and advertising (which go selling it, naming it and supporting it) and utilities (which retain product quality, post-sales). The support functions that flow into all the primary functions are the organization's infrastructure, such as the management information system that allows managers to track the market well, human resources that build the expertise required to run the business well, sourcing to buy / source products at the best price, which is becoming increasingly necessary due to challenging economic conditions and technologies.

Both allow the client to charge a fee, which comes mainly from adding the main and support functions to the valuation. Since then, the definition has been extended to account for broader units such as sub-sectors of industry. According to Kaplinsky and Morris (2000), the value chain represents the "broad range of actions needed to move a good or service from conception through the various stages of manufacturing, distribution to final customers and after-use final disposal." The actors involved play several roles in the value chain including marketing functions including production, storage, transportation and added value.

Another description is provided by Sturgeon (2001) who describes "value chain" as a chain of competitive operations, the vertical series of events leading to products and services being distributed, consumed and retained. However, Sturgeon (2001) suggests that separate value chains also share similar economic players and vary by organizational size, Sturgeon (2001) redefines the "value chain" as the series of efficient (such as value-added) operations leading to and promoting end-use. According to Sturgeon (2001), there are three dimensions of value chains, which are: hierarchical, spatial and the kind of actors involved (production actors).

Value chains are either complicated and fluid or straightforward from an operational point of view, based on their continuous availability of a range of essential resources (such as human resource needs, capital equipment and service) (Sturgeon, 2001).

The second (spatial) dimension stems from an assumption that some value chains have wide scope, others work at international scale. Often these latter chains are called global supply chains (Gerreffi, 1999).

The third dimension of the value chain includes the individuals or companies engaged in the chain of output. According to Sturgeon (2001), such players could be manufacturers (in the case of the value chain of agricultural production), vendors, retailers / wholesalers, or lead businesses.

2.6.1 Value Chain Analysis

FAO (2013) described value chain analysis as an evaluation of a portion of an economic system where upstream agents are connected by technological, cultural, geographical, institutional and social relationships in the production and distribution processes to downstream partners. The chain of value applies to both a series of interdependent economic activities and a group of vertically connected economic agents, depending on the nature of the research, the focus of the review might be on the activities or the agents (FAO, 2013).

A value chain starts with the manufacture of a primary commodity, concludes with the purchase of the finished product and involves all economic activities conducted in these phases as manufacturing, distribution, wholesale and retail. Goletti (2006) indicated that an analysis of the value chain preferably includes all participants in the value chain to deal with.

Well-functioning value chains are said to be more effective in supplying goods to customers and therefore all players, including small producers and poor customers, will benefit from the growth of the value chain (RIU, 2008). Analysis of the value chain may play a key role in defining the distribution of the benefits of actors in the chain by examining the margins and income within the chain, it is possible to assess who benefits from involvement in the chain, and which actors may gain from increased support or organization.

Where one of the segments in the value chain is inefficient, an effective marketing strategy cannot succeed. Inefficient segments are impacting producers, traders and customers along the value chain. A value chain analysis research is therefore important for identifying the segment that is inefficient. This would allow for measures designed to increase the flow of charcoal from producers to consumers.

2.6.2 Value Chain Governance

Governance refers to the management of a value chain and collaboration between actors allowing a commodity to be brought to final use from primary production (UNIDO, 2011). It could involve the power and capacity in which certain players in the value chain are exercising coordination and control along the chain. According to USAID (2007), governance of the value chain is the dynamic distribution of power and control among actors within a value chain. Although the word may have many meanings, we use it in this case to describe the sharing of a value of information and institutional standards promoted by the "governing" body.

Governance can be characterized by a range of four types of relationships (USAID, 2007):

Market relationship: arms-length transactions involving a large number of buyers and suppliers (spot market); product is undifferentiated; regular transactions are possible but not necessary; little information is exchanged between firms; interactions between firms are limited; and technical assistance is limited.

Balanced relationship: buyers and suppliers have similar alternatives-if suppliers have few customers, then customers have few suppliers; comprehensive knowledge exchange in both directions, with buyers also identifying the product (design and technical specifications); both sides have hard-to-replace capabilities; both sides are committed to solving issues through negotiation rather than through threat;
Playing.

Directed relationship: the main buyer takes at least 50% of the production of the supplier; the buyer determines the product (design and technical specification) and tracks the efficiency of the supplier; the purchaser offers technical assistance; the buyer knows more about the costs and capacities of the supplier than the buyer does; the exit possibilities of the supplier are more limited than the buyer.

2.7 Summary of Reviewed Literature

The system theory has been used to explain the effects of charcoal value chain activities on charcoal production quality and quantity. Nearly all charcoal consumed in Kenya and elsewhere in sub-Saharan Africa is in an informal structure which makes this activity unsustainable to the forest. The current charcoal production technologies by the producers are inefficient resulting in massive wastages during wood conversion to charcoal. The charcoal value chain has different actors whom have their roles and duties to ensure the flow of the chain from upstream to downstream of the chain. Tree species preference that is practiced by the actors in the value chain, affects the quality and quantity of charcoal production.

2.8 Knowledge Gaps

A critical review of relevant past studies showed that several conceptual, contextual and methodological research gaps existed in terms of the value chain activities and charcoal quality and quantity. Most studies on charcoal performance have been done in large developed economies and very few were done in developing countries. For example, Puentes-Rodriguez et al., (2017) examined fuelwood value chain analysis in Lisbon, Portugal: From production to consumption. This study was done in Portugal which is a developed country. The current study was done in Kenya which is a developing economy. As reported by Okoko et al., (2017) most studies have focused on factors such as Life Cycle Costing of Alternative Value Chains of Biomass Energy for Cooking (Owuor et al., 2018) however this failed to address the issue of quality and quantity of charcoal. This study focused on three variables related to value chain with potential influence on charcoal quality and quantity.

Most of the past studies explored the relationship of one variable with the dependent variable. To bridge this gap, this study included three independent variables, other studies methodology constituted of linear as well as multiple regression models that were run to determine the significance and relationship of individual variable with the dependent variable. Chi square test used in the current study further helped to evaluate the relationship between some parameters and charcoal quantity and quality. The reviewed literature also showed that most data was collected using interviews and laboratory tests. In the current study, data was obtained through questionnaires which provided in-depth data on the study variables.

CHAPTER THREE

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter describes the methodology that was applied to this study. This include the research design adopted, study population, the sampling procedures and sample size, data collection and procedures and instruments, data analysis and presentation.

3.2 Research Design

The study adopted descriptive research design. This research design was concerned with what exists and is related to some preceding event that has influenced the present condition. This design is informative and easier to identify the variables. In addition, it assists in collecting extensive data within short period. Descriptive research design involves collecting data through administering questionnaires or use of interviews to sample individuals (Orodho, 2008). Moreover, the design is suitable because it is fast and can accommodate large number of study units at low cost (Casley & Kumar, 1988). Kazimoto (2015) used a similar research design in his study on charcoal value chain analysis in Uyui district and Tabora municipality, Tanzania.

3.3 Research Site

The study site was the Mau west forest block in Kericho County. A satellite map image, see the Figure 3.1, at site B, that shows highest burnt disturbance in the forest, of which raises the question of how much of this burnt disturbance is related to charcoal burning. This makes the site conducive for the study.

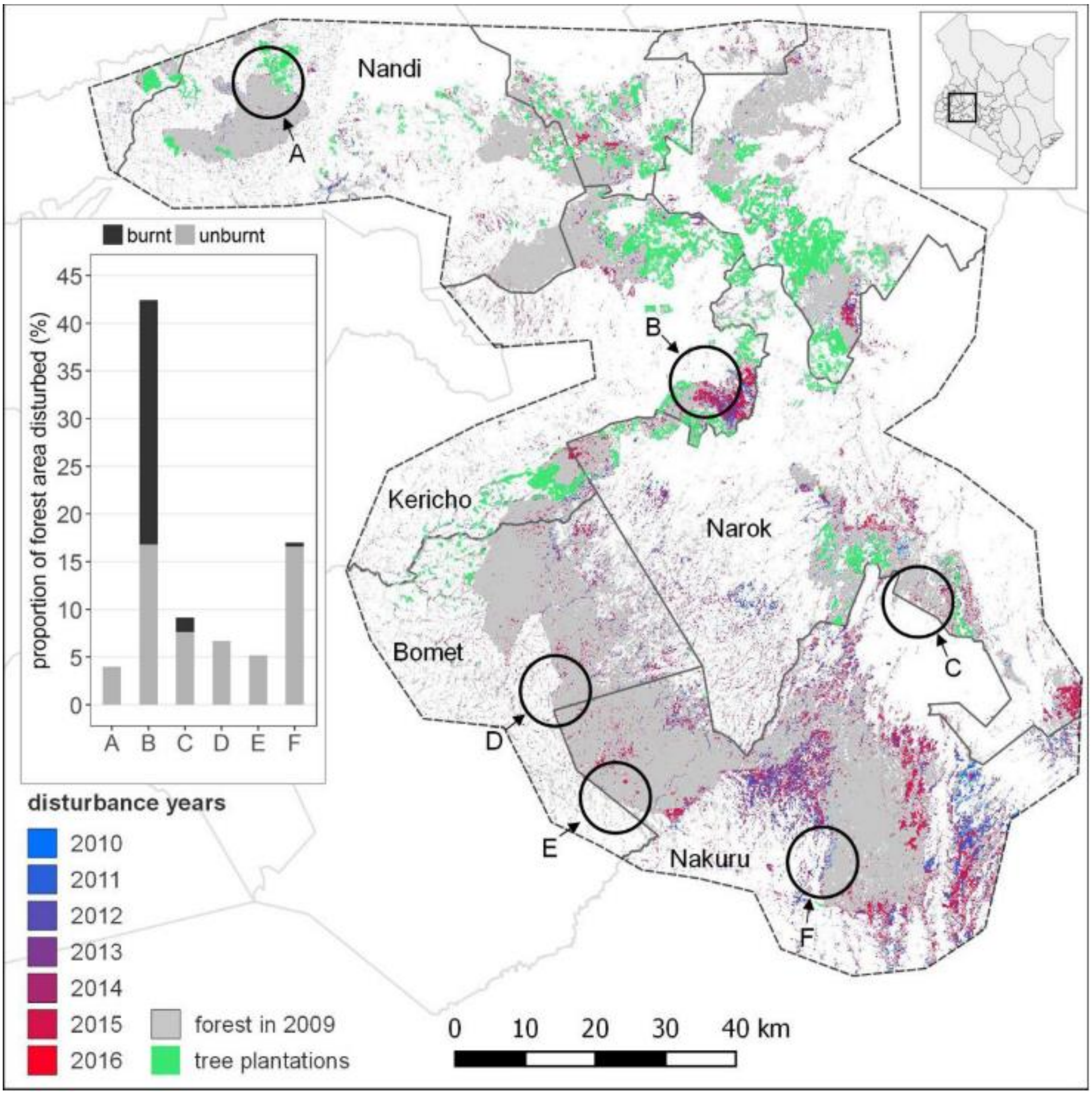

Figure 3.1: Forest disturbance mapped for 2010 to 2016 across the Mau forest.

A) South Nandi forest, B) Western Mau forest, C) Eastern Mau forest, D) South West Mau forest, E) Transmara Mau forest, and F) Maasai Mau forest. (Source: Brandt, 2017)

3.4 Target Population

The Western Mau forest block in Kericho County is 22,700 ha. The study targeted the local actors who were involved in charcoal production and selling business in areas adjacent to the Mau West Forest in Kericho County. There was no previous documented data showing the number of people involved in charcoal production and selling business in the County, and therefore the target respondents were actors residing adjacent to the forest in the following areas Kedowa/Kimugul, Chepseon, Ainamoi and Kaorora, Kapsuser, Kapkatet, Nyagacho, Kericho Kapsoit, Londiani and Litein. The total population of these areas is 289,987 (Kenya National Bureau of Statistics [KNBS], 2019). The map (Figure 3.2) shows the chosen towns for data collection for the target population.

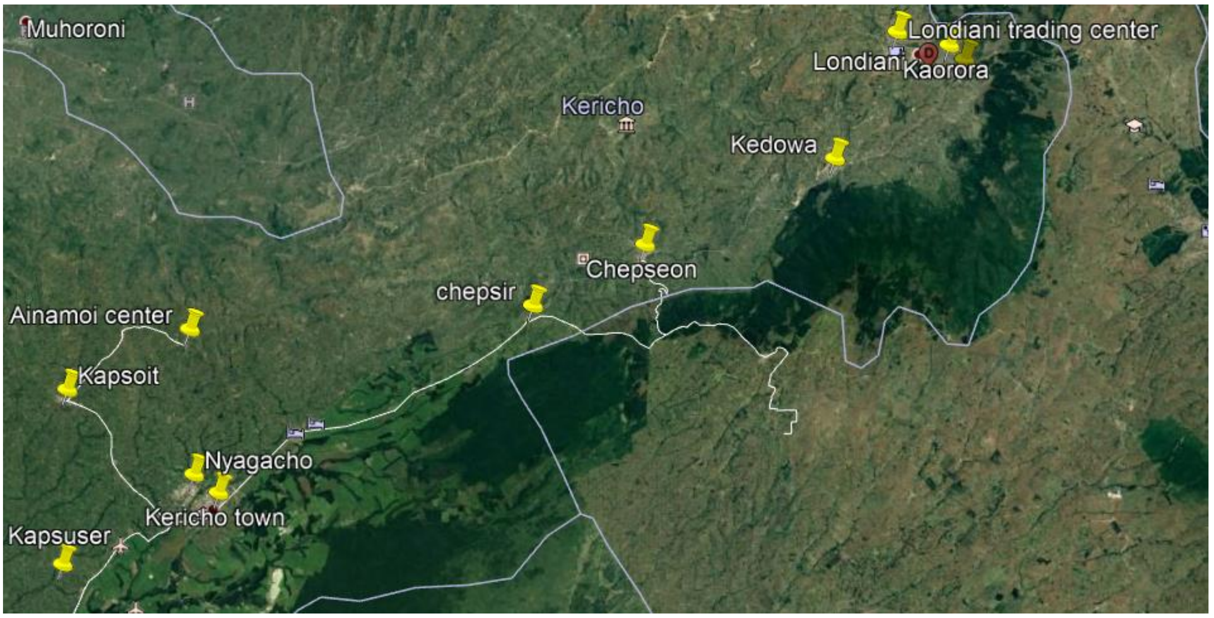

Figure 3.2: Map showing selected towns for data collection, with yellow pin marks

3.5 Study Sample

3.5.1 Sampling Procedures and Sample size

This study employed snowball sampling technique. This was as a result of the informal nature of the charcoal business in Kericho County, in addition, the moratorium in effect by the Government on logging activities. Snowball sampling was appropriate in this study as it allowed the researcher to reach the respondents, difficulties in reaching them was anticipated due to the moratorium in place by the government. Snow balling technique involved a respondent (actor in the charcoal value chain) referring the researcher to another potential actor. The kind of snowball sample procedure applied was exponential non-discriminative. The first subject recruited to the sample group provided multiple referrals. Each new referral was explored until primary data from enough samples were collected. This was specifically employed on charcoal producers as they were difficult to find.

3.6 Data Collection

3.6.1 Data Collection Instruments

Primary data were collected using different set of questionnaires (Appendix 1 – 6) that was designed with respect to each actor along the chain. The researcher used interview method through questionnaires administered to respondents who were doing different activities along the chain. This method was useful to the researcher since it helped to obtain information even from respondents who have difficulties in reading and writing. These questionnaires were supplemented by personal observation where the researcher observed various activities done by various actors in the charcoal value chain.

3.6.2 Pilot Testing of Research Instruments

A pilot testing was conducted to pre-test the research instrument to ensure that it yields correct and necessary data during the actual study. Pre-testing enabled the researcher to rectify confusing/ questions or those likely misinterpreted by respondents or contradictory with the objectives of the research. It was conducted at Molo area in Nakuru County due to the similar characteristics of charcoal trade to

Kericho County as these areas share the Mau ecosystem. Findings of the pilot survey were used to adjust the research instrument appropriately to help gather needed data.

3.6.3 Instrument Reliability

Reliability is defined as the capacity of a test or any other measurement tool to differentiate between respondents when measured twice under the same conditions. In other words, reliability is the capacity of a test to replicate the same ordering between respondents when measured twice (Berchtold, 2016). The test-retest method is more applicable to the current study and was adopted. This was done by applying paired t-test formula which is used to compare the means of two related samples. That is when you have two values (pair of values) for the same samples to calculate the reliability of the instrument. Let d represent the differences between all pairs. The average of the difference d is compared to 0. If there is any significant difference between the two pairs of samples, then the mean of d is expected to be far from 0.

To calculate the reliability, Cronbach's alpha will be applied, shown below (Chelsea Goforth, 2015):

$$\propto \frac{k \times c}{v + (k-1)c}$$

Where: k refers to number of scale of items
c refers to the average of all covariances between items
v refers to the average variance of each item

3.6.4 Instrument Validity

Validity of the research study refers to the extent at which data collected represent the phenomenon under investigation (Orodho, 2005). In order to verify the content of validity of the tools of data collection, experts in NTFPs research methodology were consulted. In addition, a pilot survey was conducted to help identify areas in the research instrument that might be ambiguous in providing the intended responses (Katzenellenbogen & Joubert, 2007). Inadequacies that were identified during pilot survey were addressed to improve the quality of the research instrument and its validity.

3.6.5 Data Collection Procedures

The data was collected from face to face interviews using semi-structured questionnaires through the help of three trained research assistants. The assistants undertook a three-day training prior to data collection exercise. They received training on accurate data recording and interviewing skills in respect to the questions in the semi-structured questionnaire was covered. The researcher observed a close supervision of the assistants during data collection.

3.6.6 Measurement of Tree Wood Quality and Quantity

Laboratory tests determining charcoal quantity and quality were carried out at Burn Manufacturing ltd in Ruiru. 'Based in Ruiru, Kenya, BURN Manufacturing designs, produces and distributes Kenya’s bestselling, most durable and economical charcoal and wood cook stoves that also dramatically reduce harmful smoke emissions which can cause significant health problems, even death. With more than 460,000 stoves sold since 2013, BURN has established itself as the most trusted *jiko* brand thanks to our unwavering commitment to innovative research and design, manufacturing excellence, and customer care. BURN is also the only *jiko* company which manufactures all of its products in sub-Saharan Africa's only state-of-the-art clean cook stove manufacturing facility.'

Tree Species Selection and Fieldwork

The selection of trees was based on a directed sampling whereby two trees were taken per species with the following criteria: health, vigour, lack of bifurcation and representative of the study area, from 20 to 30 cm in diameter at breast height and with heights between 10 and 15 m. Logs of 2.5 m in length were taken from each tree and a slice of 2 cm was cut on each side. Moreover, the sapwood and heartwood were separated. To determine the ash and volatile content, the material of the two slices was splintered. It was mixed and ground in a Wiley-type mill, subsequently sieved in No. 40 and 60 mesh, and used the material that was retained in the 60 mesh (Honorato-Salazar et al. 2015).

Wood Basic Density

Twelve wooden cubes of 2 cm per side were prepared for each species and the wood basic density was determined in samples of sapwood and heartwood of each species by ASTM D143-94: 2007.

Elaboration and Yield of Charcoal

Charcoal was elaborated on a laboratory scale with 12 cubes of wood per species, 1.5 cm per side; these were introduced in metal tubes of 3 cm in diameter by 11 cm of length. The cylinder with the wooden cubes (3 to 5 cubes) was subjected to combustion in a Thermolyne® digital furnace at a temperature of 450°C ± 10° C for 30 minutes. The yield was evaluated by Eq. 1 (Vogel and Wolf 1986, Heya et al. 2014).

$$Yield = \left(\frac{Anhydrous\ Charcoal\ weight}{Anhydrous\ wood\ weight}\right) \times 100\ (\%) \qquad (1)$$

Energy Characterization of Wood and Charcoal

The moisture content of the wood and charcoal was determined with ASTM D1762-84: 2007. The material was conditioned in the laboratory environment and then used in an electric furnace at 105°C. Volatile matter was determined by ASTM E872-82: 2006 at temperature of 950ºC.

Ash content was determined according to ASTM D1102-84 R07: 2007. The sample was used without volatile material in a furnace at 600°C for 6 h. Ash content was calculated to the anhydrous weight of the initial sample.

High heating value (HHV) was determined in samples (1.5 cm) of sapwood and heartwood of wood and charcoal by using flat jacket calorimeter 1341 (Parr USA) (See appendix III). According to Purohit and Nautiyal (1987) the high heating value, normal density and ash content are related by means of the fuel value index (FVI) by Eq. 2; where HHV: High heating value (MJ.kg-1), ND: Normal density (kg.m-3), AC: Ash content (g.g-1), MC: Moisture content.

$$FVI = \frac{HHV \times ND}{AC \times MC} \qquad (2)$$

Charcoal Production and Fieldwork

The billets were transported to the kilns site. The diameters were measured at the middle of the billets and the volume was determined according to Huber formula. The billets were sorted into three diameter categories: small size (2.5-8.9 cm), medium size (9.0 cm-17.9 cm) and large size (18.0 cm and above) using a caliper.

The billets were stacked in cubic meters for the sake of calculating stacking conversion factor. A weighing scale of 220 pounds was used for weighing the billets.

The billets were air-dried before carrying out the carbonization process. The process of carbonizing is described below for the three kiln types.

Metal kiln

For the three size classes the kiln was prepared in a good manner, taking care that the soil is compact and there is no cracks. Then the kiln fitted on eight inlet/outlet channels at the same distance between them. The height of in/out let channels is five centimeters so the kiln was five cm from the ground.

Billets of known weight, volume and length were put vertically (for a height of one meter), then horizontally up to the edge of the cylinder and lastly took the shape of the conical cover in the upper part. A vent was left all through the kiln from the bottom upwards and filled with straw. The conical cover was put and four smoke stacks were fitted onto alternate air channels.

The ignition was encouraged by gasoline oil. When the fire caught, after 20-30 minutes, the vent on the upper part of the conical cover was shut and the kiln was sealed with silt all around to prevent any entering of air except through the channels. The smoke stacks were changed periodically to give equal air for all directions of the kiln so the burning was controlled by limiting and regulating the amount of air entering the kiln.

Great attention was taken to avoid any break down. After the color of the smoke changed to bluish all vents were sealed. The bluish color appeared after kiln ignition by 50, 46 and 31 hours for the large, medium and small-diameter billets, respectively. After two days, the kiln was opened and charcoal was put in sacks and weighted.

Traditional kiln

The billets were stacked starting from the centre outwards. The space between the billets was filled with dry straw for the small diameters and with dry straw and branches (locally known as a sotaf) for the large and medium diameter billets.

A tunnel was left away from the wind direction leading to the central straw stack. The kiln was then covered with dry straw and the upper part was covered with grass and silt. The central straw stack was ignited and then supervision was taken day and night. When carbonization ceased a thick layer of silt was put on to prevent any entering of air. After the kiln cooled down the kiln was opened.

Oil drum kiln

The length of the drum was 85 cm and the billets were 82 cm long. The space between the billets was filled with dry straw; two iron bars were put radial to the vent to prevent billets from falling. After the caught, the drum was rolled up down and a thin silt layer was used to seal the vent all around to avoid any entering of air. Only small-size billets were used in this procedure.

Charcoal Yield

In order to evaluate the yield of the charcoal, the produced charcoal was weighed using a 100-kg balance. The weights for charcoal, fines and unburned wood were recorded separately. The net charcoal produced was determined as the ratio of the net weight of charcoal to the weight of the billets, excluding the fines and unburned wood.

Measures of Charcoal Properties and Type of carbonization Kiln

To test some of the physical and chemical properties of the produced charcoal, three samples were randomly selected to represent each combination kiln type and billets size. The physical properties included moisture content, density, calorific value, ignition time, burning time, water boiling time, and chemical properties, including volatile substances, ash and fixed carbon, which were measured according to standard procedures (ASTM D: 1762, 1990).

Moisture content

The moisture content was determined as the weight loss of powdered charcoal at 105o C. Twenty one empty crucibles were oven-dried and weighed individually using a sensitive balance. Then from each of the three randomly selected samples for each kiln type and billet size, one gram of powdered charcoal (21 samples) was put in one of the crucibles. The specimens were placed in a universal drying oven with temperature set to 105o C over night until the specimens reached a constant weight and that was after about 24 hours. The crucibles were cooled in a desiccator containing copper sulphate as drying agent for an hour. The difference between the weights before and after drying was the amount of the moisture content, and it was given as a percentage of the oven-dry weight.

Volatile substance content

ASTM procedure D: 1762 (1990) was used to determine volatile substance content, ash content, fixed carbon. To determine volatile content, the muffle furnace was heated to 950o C then the crucibles used for the moisture determination were preheated with lids in place and containing the samples as follows: with the furnace door open, for two minutes, on the outer edge of the furnace (300minutes on the edge of the furnace (500o o C) and then for three C). Then the samples were moved to the rear of the furnace for six minutes and then cooled in a desiccator. Then the crucibles were reweighed and the differences between these weights and the respective initial (oven-dry) weights represent the weight of volatile matter. Volatile matter content was calculated as the percentage of these weights and respective ones of the oven-dry charcoal.

Fixed carbon content

Fixed carbon was calculated as the difference of 100 minus the sum of the volatile and the ash content.

Ash content

The preceding samples were further heated for six hours in a furnace oven at 750○ C. The samples were cooled for an hour and then weighed. The difference between these weights and the empty crucibles was calculated as the weight of the

3.7 Data Analysis

After the data collection exercise, data cross checking was done to identify possible errors before data entry. Raw data was coded accordingly. This was followed by entering the coded data into MS-Excel spreadsheet and data cleaning done prior to data analysis. The Statistical Package for the Social Sciences (IBM SPSS version 26.0) computer package was used to analyse the data. Descriptive statistics such as frequencies, percentages, mean scores, standard deviation, cross tabulations and charts were derived from the responses to summarize data from various variables. Inferential statistics was applied by finding the Chi- square test for the significance of relationship between years of experience and height at which the tree is cut, also finding the correlation between charcoal production and bags produced in wet and dry seasons.

: Data Analysis Summary and Statistics applied for each research objective

	Specific Objective	Independent Variable	Dependent Variable	Statistics Used
(i)	To evaluate the influence of tree harvesting methods on quantity of charcoal produced in Kericho County.	Wood Harvesting	Charcoal production	Descriptive statistics Inferential statistics (Chi-square test)
(ii)	To evaluate the influence of tree harvesting methods on quality of charcoal produced in Kericho County.	Wood Harvesting	Charcoal production	Descriptive statistics Inferential statistics (Chi-square test,Corelation)
(iii)	To determine the influence of earth mound kiln on charcoal quality in Kericho County.	Earth Mound Kiln	Charcoal production	Descriptive statistics Inferential statistics (Corelation)
(iv)	To determine the influence of earth mound kiln on charcoal quality in Kericho County.	Earth Mound Kiln	Charcoal production	Descriptive statistics Inferential statistics (Corelation)
(v)	To determine influence of tree species quality of charcoal in Kericho County.	Tree species perception	Charcoal production	Descriptive statistics
(vi)	To determine influence of tree species on quantity of charcoal in Kericho County.	Tree species preference	Charcoal production	Descriptive statistics Inferential statistics (Chi-square test, T-test)

3.8 Legal and Ethical Considerations

Research approvals and permits were obtained from the relevant institutions. The success of this study was highly dependent on the actors that participated in charcoal production. Caution was of utmost importance to protect the identity of the respondents who were providing the information, due to the sensitive nature of charcoal production situation in the country with the charcoal ban in effect. No one was forced or coerced in data provision.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter deals with the analysis of data collected, presentation and discussion of the results obtained. The data analysis is in harmony with the specific objectives where patterns were investigated, interpreted and inferences drawn on them. Specifically, the study sought to evaluate the effects of tree harvesting methods on quantity of charcoal, to evaluate the effects of tree harvesting methods on quality of charcoal, to determine the effects of earth mound kiln on charcoal quality, to determine the effects of earth mound kiln on charcoal quantity, to determine the effect of tree species on quality of charcoal and lastly to determine the effect of tree species on quantity of charcoal.

4.2 Demographic Characteristics

This section presents results regarding respondents' age, gender, education background, ethnic group and category in charcoal value chain.

4.2.1 Age of the Respondents

The respondents were asked to state their ages. The results are shown in Table 4.1

Table 4.1: Age group of Respondents

Age Group	Frequency	Percent (%)
Under 30	71	23
30-40	130	42
40-50	50	16
50-60	31	10
Over 60	28	9
Total	**310**	**100**

The study found out that the majority (65 %) of the respondents were under the age of 40. The youth (under 30 years) participate less than the adults (30-40) as they find the job too tedious with too many risks and profits are not guaranteed. They move to the cities to look for office jobs or other forms of employment. The adults in the age bracket between 30 and 40 years were more likely to participate in charcoal production the most because they have families to provide for and it was the easier option for them since they did not have the high-level education to qualify for office jobs.

4.2.2 Gender of Actors in the Charcoal Value Chain

The gender of the participants was noted during the data collection and the results are summarized in Table 4.2.

Table 4. 1: Gender of the Respondents

Gender	Frequency	Percent
Male	227	73.2
Female	83	26.8
Total	310	100.0

The majority (73.2 %) of the respondents were male, while 26.8 % were female. This is due to the cultural element that charcoal burning is a man's work but the trend and believes are changing so that a significant number of females have taken up charcoal burning as a coping strategy.

The respondents were divided by gender according to the activities they performed in the charcoal value chain and the results are presented in Table 4.3.

Table 4.3: Gender of Actors in the Charcoal Value Chain

Gender	Producer (%)	Transporter (%)	Broker (%)	Trader (%)	Seller (%)	Total (%)
Male	51	8	6	7	1	73
Female	7	0	0	0	20	27
Total	**58**	**8**	**6**	**7**	**21**	**100**

The result of Table 4.3 indicate that the majority (51 %) of the males were charcoal producers, while only 7 % of the female participated in producing the charcoal. The women (21 %) participated in the selling of the charcoal within the homesteads and by the roadside.

4.2.3 Education Level of Respondents

The respondents were asked to state the highest level of formal education they had attained and the information was analysed and is presented in Table 4.4.

Table 4.4: Highest Level of Formal Education Attained by the Respondents

Formal Education Level	Frequency	Percent
No Formal Education	30	9.6
Lower Primary (4 years)	66	21.3
Upper Primary (8 years)	144	46.5
Secondary (Form 4)	53	17.1
Tertiary	17	5.5
Total	**310**	**100.0**

The respondents who had completed the primary level were 46.5%, while the secondary level were 17.1%, and tertiary 5.5 %. The group that attained the level of lower primary were 21.3 % and the ones who did not attend any formal schooling were 9.6%. This implies that the progression to secondary level is low (17.1 %), leaving 77.4 % to seek employment in business and charcoal production to sustain themselves and their families, as other jobs are hard to find.

4.3 Socio-economic Characteristics of the Respondents

This section dealt with the aspect of land ownership and economic activities the respondents were engaged in

4.3.1 Land Ownership and Shelter

About 80 per cent of the respondents said that they did not have any land on crops showing that charcoal burning was a major occupation for them. At least some 5 per cent had between 1-2 acres of cropland while 15 per cent had less than one acre on crop land. Such crop land sizes, considering the arid conditions of the area are not economically viable for any reliable food crop, thus hunger here could be a cyclic phenomenon, and has made people resort to charcoal burning.

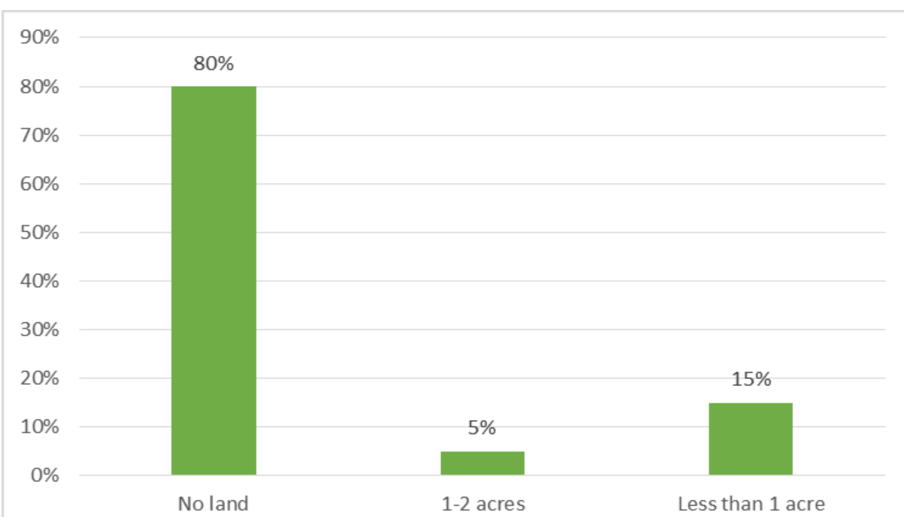

Figure 4.1: Land ownership and size as an influence of socio economic status

These charcoal burners in this area do not mind the extent of vegetation destruction since they do not own any land and they lack proper formal education. About 75 per cent are permanently doing charcoal burning and only 35 per cent are satisfied with the income they get from charcoal selling. Actually the income is so low compared to the strenuous labor involved with allot of heat.

All the living structures of the respondents are temporary ones with 55 per cent being of mud walled and 45 per cent timber-wall and all have earth floor. The respondents' income level is too low to put up a better living structure and also they have no security of land as most of them do not own land there. Only 40 per cent said that they were satisfied with the housing living conditions and these were mainly the victims of war who viewed life there to be of better value than their place of origin. Only 30 per cent of the respondents said that they like living in the area because they are used, and life there is better than their area of origin, and there was enough land to burn charcoal. The rest did not like living there because of draught/water and hunger, insecurity, communication problem and lack of permanent jobs. They respond to these problems by charcoal burning and selling, casual jobs and a few pray to God.

4.3.2 Types of Categories of Actors in the Value Chain

The respondents were asked to state at which activity were involve in their activities on the charcoal value chain. The information was analysed and its frequency distribution is shown in Table 4.5.

Table 4.5: Type of Categories of Actors

Categories of Actors	Frequency	Percentage
Producer	179	58
Seller	65	21
Transporter	25	8
Trader	22	7
Broker	19	6
Total	**310**	**100**

The results in Table 4.5 indicate that the majority (58 %) of the participants, were charcoal producers, 21 % of the respondents were charcoal sellers while 6 % of the respondents were brokers. In addition, the study sought to establish the gender dynamic data of the categories.

4.3.3 Ethnic Diversity of Actors in the Value Chain

Each respondent was asked to state their ethnicity. The information was summarized using a frequency distribution table. The results are shown in Table 4.6.

Table 4.5: Ethnic Diversity of Actors in the Value Chain

Ethnicity	Frequency	Percent
Kikuyu	127	41
Kalenjin	81	26
Kipsigis	43	14
Luo	22	7
Kisii	19	6
Luhya	19	6
Total	**310**	**100**

According to Table 4.6, 41 % of the respondents were the Kikuyu, 26 % were Kalenjin, 14 % were Kipsigis, 7 % were Luo while 6% were Kisii and Luhya respectively. The results indicated that Kericho County is ethnically diverse.

4.4 Influence of Tree Species Utilized on the Quality of Charcoal Produced

The first objective was to determine the effects of tree species on quality of charcoal production. The sections include: (i) Effect of perception of tree species on quality of charcoal. (ii) Effect of preferred tree species in study area by the different actors in the value chain on charcoal production.

4.4.1 Tree Species Preference and Quality of Charcoal

The study sought to establish species of trees that charcoal producers preferred, the results are as shown in Table 4.6.

Table 4.6: Tree Species Preference

Species Perception preference	Frequency	Percent
Both Exotic and Indigenous	43	14
Indigenous	90	29
Exotic	177	57
Total	**310**	**100**

Fifty Seven percent (57%) of the producers interviewed preferred exotic species, 29% indicated that they preferred indigenous species while 14% indicated they preferred both exotic and indigenous species. However, majority of the respondents cited that indigenous species produced the best quality charcoal compared to exotic species. Due to the current circumstances of the charcoal industry, majority are using a mix of both exotic species with indigenous species and shown Table 4.6. The reasons being that it is difficult to find their preferred species.

4.4.2 Preferred Tree Species in the Study Area by Different Actors in the Value Chain and its Effect on Quality of Charcoal

The retailers were asked to state their preferred species for charcoal production. The information was then summarized using a graph as shown in Figure 4.2:

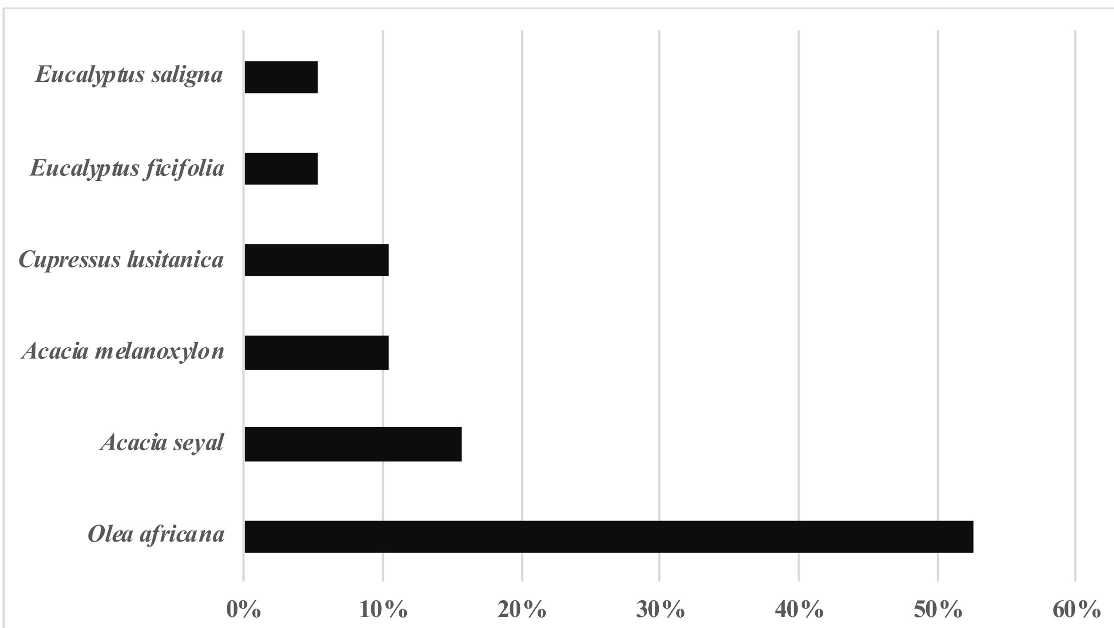

Figure 4.2: Preferred species by Retailers

According to the survey, the retailers preferred indigenous species to exotic species. The interviewed retailers preferred *Olea Africana* (Figure 4.2) indicated at 53%, flowed by *Acacia seyal* at 16%, which are indigenous species. *Cupressus lusitanica* and *Acacia melanoxylon* were the most popular exotic species indicated at 11%. This is due to quality of charcoal produced from indigenous species is of more superior quality, in terms of burning which lasts longer than those made from exotic species (Adeniji, Zaccheaus, Ojo, & Adedeji, 2015).

The Producers were asked to state their preferred species for charcoal production. The information was then summarized using a graph. The results are shown in Figure 4.3.

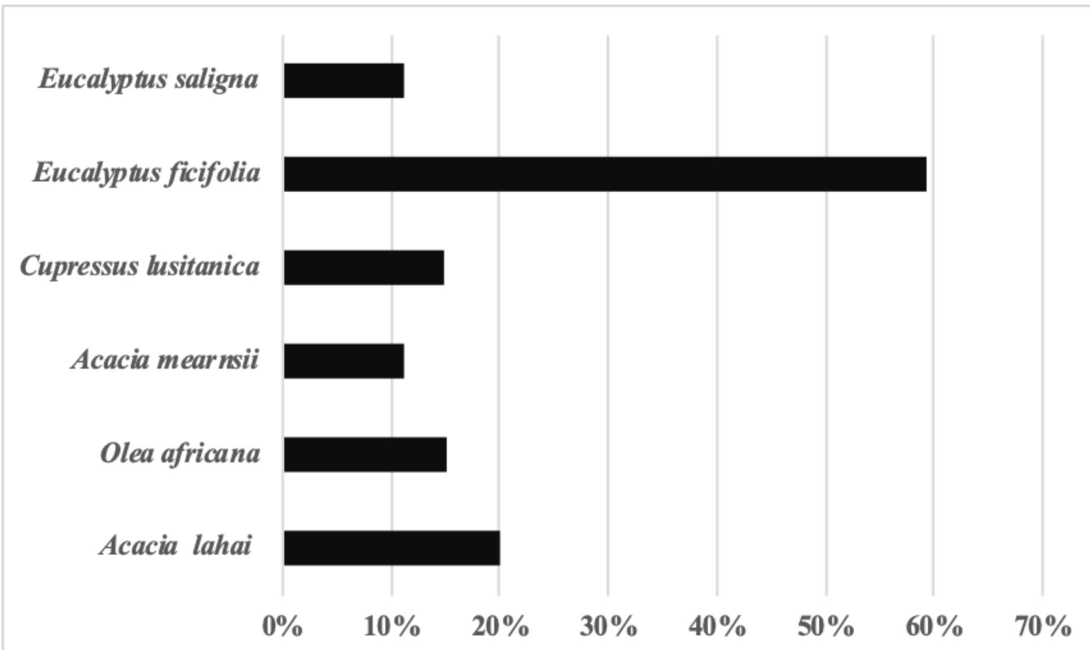

Figure 4.3: Preferred Species by Producers

Charcoal producers in the study areas used both exotic and indigenous trees to produce charcoal. They have strong preference for *Eucalyptus ficifolia* which is an exotic species. It is also noted that the indigenous species of *Acacia lahai* which is most preferred indigenous species at 20%. This shows that indigenous species are harder to get, and the producers use a mix of the two species to fill demand of charcoal from the market (Onekon & Kipchirchir, 2016).

The traders were asked to state their preferred species for charcoal production. The information was then summarized using a graph. The results are shown in Figure 4.4.

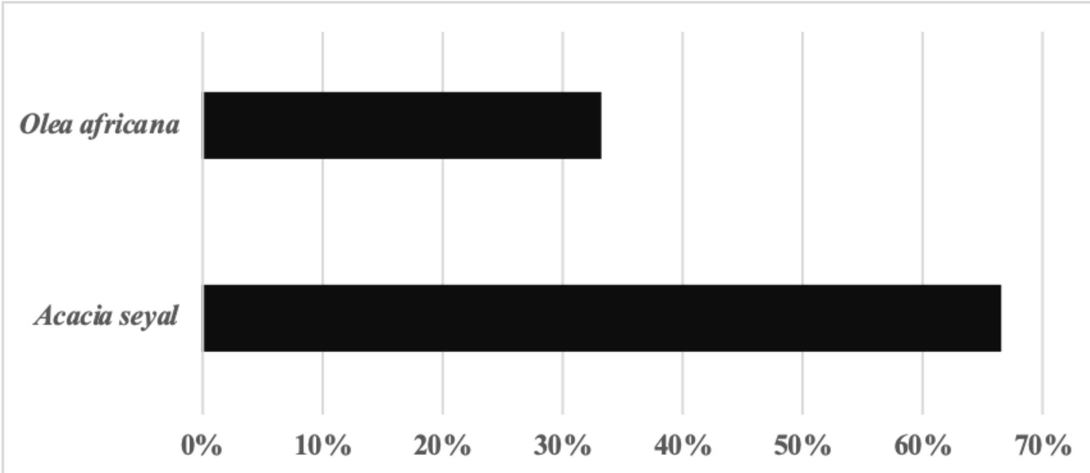

Figure 4.4: Preferred Species by Traders

According to the survey, charcoal trader respondents have a preference for *Olea Africana* (indigenous) and *Acacia seyal* (indigenous). The respondents also mentioned that they experience difficulties acquiring charcoal made from these species due to their depletion.

Table 4.7: A Summary Table of Preferred Species by the Actors in the Value Chain

	Retailer		**Trader**		**Producer**	
Tree Species	**No.**	**%**	**No.**	**%**	**No.**	**%**
Olea africana	10	53	1	33	4	15
Eucalyptus ficifolia	1	5	-	-	16	59
Eucalyptus saligna	1	5	-	-	3	11
Cupressus lusitanica	2	11	-	-	4	15
Acacia melanoxylon	2	11	-	-		
Acacia Mearnsii	-	-	-	-	3	11
Acacia lahai	-	-	-	-	2	20
Acacia seyal	3	16	2	67	-	-

Acacia lahai and *Eucalyptus ficifolia* are the most preferred species by producers, but as mentioned before, they do a mix of these species, to fill market demand and also because these species are easily to be found by the producers. Other actors do have a preference but if the species is not easily found the producer will produce charcoal from the species that can be easily found. It is perceived by the actors that indigenous species produce good quality charcoal, hence their high preference. In this case, the said species that produce better charcoal when burned (indigenous), is said to burn for a longer period, hence knowing which species are good for charcoal production and which is not. Indigenous species are also known to have higher carbon value than exotic species hence, producing better charcoal (Onekon & Kipchirchir, 2016).

The study revealed that majority use exotic species exclusively. Others mixed indigenous and exotic species to enable demand satisfaction in the market. Although the perception of the producers was that indigenous species produces high quality charcoal, from the findings it proves that the indigenous species is scarce hence the options mentioned of preference.

Different actors preferred different species. Producers preferred to mix indigenous and exotic species, in order to meet the market demand. Although, they mentioned they preferred *Eucalyptus ficifolia.* Traders and retailers preferred *Olea Africana*. This can be attributed to the different experiences they have had on acquiring charcoal made from these species. From the results, it is noticed that *Eucalyptus ficifolia* is found easily than *Olea Africana.* This can be attributed to the preference of the actors, especially the producers since they venture into the forest to acquire the wood for charcoal production.

Acacia species are most preferred despite the ban. Kenya Forest Service and the Kenya Charcoal Regulations prohibit the use of sandal wood and Acacia species in charcoal production except in special cases, where permit must be obtained from KFS (KFS, 2013).

4.5 Influence of Tree Species on Quantity of Charcoal Production

The first objective was to determine the influence of tree species on quantity of charcoal production. The sections are: (i) Preferred tree parts used for charcoal production. (ii) Preferred height to cut trees. (iii) Correlation on tree species and number of bags produced in wet and dry season.

4.5.1 Preferred Tree Parts used for Charcoal Production

The respondents were asked to state their preferred tree parts to use for charcoal production. The results are shown in Table 4.8.

Table 4.82: Tree Parts used for Charcoal Production

Preferred Tree Parts used to make charcoal	Frequency	Percent (%)
Dead wood branches	202	65
All parts of deadwood and live trees	56	18
Live trees -stems and branches	56	18
Total	**310**	**100**

The study revealed that the interviewed producers mostly use deadwood branches for making charcoal. This is due to its availability and ease to acquire. This also reveals that the charcoal producers use the whole live tree if they cut it down and when they can’t cut the whole tree down, they use the stems and branches. The aim was to ensure quick wood harvesting and charcoal production due to the charcoal ban in effect which has intensified guard inspections in the government forest.

Table 4.93: Chi-square Test Cross Tabulation of Preferred Tree Parts and Species Preferred

		n	[%]	Chi Square (χ2)	P-
All parts of deadwood	Exotic	15	68.1		
and live trees	Indigenous	7	31.1	1.345	0.001
Dead wood branches	Exotic	4	66.7		
	Indigenous	2	33.3	1.743	0.010
Live trees stems and	Exotic	4	66.7		
branches	Indigenous	2	33.3	1.982	0.021

Pearson's Chi-square test was carried out in a cross-tabulation between parts of trees preferred and species preferred. This was done to test the hypothesis that parts of trees used, and species preferred are independent. The results showed statistically significant difference (χ^2 (2) $p < 0.05$ at 95%). Thus, we can say that parts of trees used, and species preferred are not independent. We can infer that tree parts from exotic species are more likely to be harvested than those from an indigenous tree.

The Kenya Forests Act of 2005 specified that permitted logging, which is the only legal way of commercially extracting forest products, must not cause damage to trees, soil or other forest resources (GOK, 2009). It continued: vulnerable, endangered and protected plant species must not be used for charcoal production either. Majority of the producers used deadwood branches to produce charcoal. This was because of the harsh environment in the charcoal industry due to the charcoal ban in effect which makes many producers shy away from felling trees in the government forest for fear of getting caught. They mentioned they cannot be penalized for collection deadwood branches from the forest, as they acquire permits to collect firewood from the forest at a fee of 100 kshs. This shows that less charcoal is being produced due to affected sources of wood from the forest.

4.5.2 t-test on Trees Species and Number of Bags Produced in Wet and Dry Season

Using the information stated by respondents on preferred species and number of bags produced in the wet and dry season, the information was analyzed using t-test between these variables, to compare the difference in these variables. The results are shown in Table 4.10 and 4.11.

Table 4.10: Number of Bags Produced in Wet and Dry season Statistics

Season	Number of bags	Mean	Standard Deviation	Std. Error Mean	Levene's test for equality variance			
					F	p	t	df
Dry	1093	32.21	85.61	85.61	102.98	0.001	*0.48*	49
Wet	795	24.24	43.64	43.64				

The mean number of bags produced during the wet season was 32.21, and the mean number of bags produced during the dry season was 24.24. To test the hypothesis that the wet and dry season production showed statistically significant difference, an independent *t*-test: two-sample assuming unequal variances was performed. The results indicated that there existed a statistically significant difference between wet and dry season since p value was less than 0.05. The results in Table 4.10 indicated that more bags were produced during the dry season.

Table 4.11: t-test on Species preferred During the Wet and Dry Season

Season	Species selected	Number of bags	Mean	Standard Deviation	Levene's test for equality variance			
					F	p	t	df
Wet	Exotic	365	112	44.4	42.98	0.008	0.15	7
	Indigenous	749	101	180.3	34.34			
Dry	Exotic	371	114.7	64.6	37.98	0.005	0.64	8
	Indigenous	466	62.6	85.4	46.98			

In the wet season, the number of charcoal bags produced was associated with exotic species *M* = 112 (*SD* = 44.4). By comparison, the number of charcoal bags produced was associated with indigenous species *M* = 101 (*SD* = 180.3), with a numerically smaller mean of charcoal bags produced in wet season. To test the hypothesis that there is no statistically significant difference between exotic and indigenous species, an independent t-test: two-sample assuming unequal variances was performed.

The results indicated that there was no significant difference between *exotic and indigenous species* since p values were greater than 0.05. This implied that charcoal producers carbonized exotic species and indigenous species for charcoal regardless of the season.

In the dry season, the number of charcoal bags produced was associated with exotic species *M* = 114.7 (*SD* = 64.6). By comparison, the number of charcoal bags produced was associated with indigenous species *M* = 62.6 (*SD* = 85.4), with a numerically smaller mean of charcoal bags produced in wet season. To test the hypothesis that there is no statistically significant difference between exotic and indigenous species, an independent t-test: two-sample assuming unequal variances was performed. The *t*-test was associated with a non-significant effect t (8) = 0.64, p = 0.005. Thus, the charcoal bags produced from exotic species was associated with a statistically non-significant mean difference from charcoal bags produced from indigenous species in the wet season. The results show that in both seasons, that there is no significant statistical difference in the means of charcoal bags produced from exotic species and indigenous species. This can be due to the same kinds of species used to produce charcoal in the wet and dry seasons hence the small difference in means of number of charcoal bags produced.

4.5.3 Tree Species and Charcoal Quantity (Yield)

The charcoal yield for five tree species utilized for charcoal making in the western Mau Forest were determined and the results are summarized in Table 4.12.

Table 4.12: Tree Species and Charcoal Yield

	Charcoal Yields		
Tree Species	**Sap Wood**	**Heart Wood**	**Average**
Olea africana	26.30 (0.92)a	26.08 (1.32)a	26.19 (1.09)A
Acacia	30.06 (0.96)a	7.80 (0.90)b	28.93 (1.47)B
Trichocladus ellipticus	27.57(0.72)a	26.71 9 (0.72)a	27.14 (0.82)A
Euclea divinorum	30.01 (0.28)a	29.46 (0.84)a	29.73 (0.67)B
Acokanthera friesiorum	31.55 (1.08)a	36.69 (1.29)b	34.12 (2.92)C

Values in parentheses represent the standard deviation. Equal upper case letters in each column represent statistical equality per species (p=0.05). Equal lower case letters in each column represent statistical equality between sapwood and heartwood within each species (p=0.05).

The highest yield of charcoal was obtained with wood of *Acokanthera friesiorum* (Murichu) (34.12%). This species was statistically superior to the others (Table 4.12).

The yield may vary due to factors such as equipment, processes, temperature and rate of heating, physical characteristics and chemical composition of the species and moisture content (Demirbas 2004). According to Rivera and Uceda (1987), a higher yield is related to a higher extractive content.

The yield of the five species, with the exception of *Acokanthera friesiorum* (Murichu) (34.12%) is within the interval reported by Heya et al. (2014) for five species (20.96-30.15%). It should be noted that, as in the present study, in the one conducted by Heya et al. (2014), charcoal was elaborated on a laboratory scale in a furnace at a controlled temperature. However, under real conditions, the main problem is the low carbonization yield because there are no regulations in the charcoal production process (Bustamante-García et al. 2013). Moreover, the yield may be affected by the species, dimensions of the firewood or the type of kiln (Carrillo-Parra et al. 2013)

4.6 Influence of Harvesting Preferences on Quality of Charcoal Production

The second objective was to evaluate the influence of tree harvesting methods on quality of charcoal production. The study sought to determine the effect of wood harvesting preferences on the quality of charcoal production. This section discusses preferences that affect wood harvesting in terms of charcoal quality. This section includes: (i) Preferred girth of tree cut in wood harvesting (ii) Years of experience of the charcoal producer.

4.6.1 Preferred Size of Girth to Cut Trees

The study sought to establish the height of trees that producers most preferred for charcoal production. The results are shown in Table 4.13.

Table 4.13: Size of Girth of Tree Cut and Charcoal Quality

Girth in cm	n	%	Chi-square (χ^2)	p
≥ 15	21	21	11.848	0.01
15 -30 cm	68	68		
≤ 30 cm	11	11		

Majority of the respondents indicated that they considered tree cuts with diameter/girth size ranging between 15 -30 cm for they produced quality charcoal (68, 68.0%) (Table 4.13). The chi square statistic indicates statistically significant relationship between girth size and quality of charcoal [χ^2=11.848, $p<0.01$].

4.6.2 Years of Experience of the Charcoal Producer

The respondents were asked to state how many years they have in producing charcoal. The information was summarized using a distribution frequency table. The results are shown in Table 4.14:

Table 4.14: Years of Experience of the Charcoal Producers

Years of Experience	Frequency	Percent (%)
1-10	22	69
10-20	7	22
20-30	2	6
30-40	1	3
Total	**32**	**100**

Majority of the producers (69%) have under 10 years of experience in the charcoal production section. This means their technical skills are still on amateur level. This affects the quality of charcoal that is produced. The responses on preferred girth of tree to be cut by the respondents was cross tabulated with years of being in the charcoal industry and they were shown in Table 4.15:

Table 4.15: Correlation analysis of Preferred Girth to Cut Trees and Years of Experience Table Statistics

Correlation	Preferred Girth Size
Years of Experience	0.064
r	0.06
p	0.72

Thirty-two charcoal producers were surveyed about their years of experience in the charcoal industry and their preference of cut-height of the tree. The results indicated that there was no relationship between years of experience and preference of height to cut a tree ($p > 0.05$). The study showed that producers preferred cutting trees between 15-30 cm girths, which, hence the choice of use of machetes, axes, and hoes as tools to cut down these trees. This selectivity of tree girths of 15-30cm tends to lead to destruction of the forests as particular species tend to be targeted for cutting.

4.6.3 Tree Species and Charcoal Quality

Tree Species and Moisture Content

The moisture content of the five tree species used in charcoal making in western Mau was analysed and the results are given in Table 4.16.

Table 4.16: Moisture Content of Tree Species

Tree Species	Moisture Content		
	Sap Wood	**Heart Wood**	**Average**
Olea africana	1.45 (034)a	1.73 (0.22)a	1.59 (0.31A
Acacia	2.32 (0.58)a	2.33 (0.80)a	2.32(0.80)B
Trichocladus ellipticus	3.70 (0.49)a	3.65 (0.25)a	3.67 (0.36)C
Euclea divinorum	3.46 (0.20)a	3.44 (0.32)a	3.45 (0.25)C
Acokanthera friesiorum	2.15 (1.02)a	2.52 (0.65)a	2.33 (0.82)B

Values in parentheses represent the standard deviation. Equal upper case letters in each column represent statistical equality per species (p=0.05). Equal lower case letters in each column represent statistical equality between sapwood and heartwood within each species (p=0.05)

The analysis of variance of the moisture content in charcoal showed no statistical differences between type of wood of the five species (p>0.05) (Table 4.3). The comparison test of means of moisture content between species indicates: *the Olea africana* was statistically lower to the rest of species. Based on the moisture content, *the Olea africana* is more efficient as a fuel, because the net calorific value increases with lower moisture content. In all studied species, the moisture content was less than 5%. In general, moisture contents of less than 8% are required to reduce the consumption of material to evaporate the water and also with these values a charcoal less susceptible to attack by biological agents is obtained (Heya et al. 2014).

Tree Species and Volatile Matter

The volatile matter inside the five different tree species was determined and the results are summarized in Table 4.17.

The volatile content for sapwood and heartwood of the five species averaged 80.86% (Tab. 4.17). It has been reported that species with less volatile content are better as fuels because they promote cleaner combustion (Heya et al. 2014). By wood type, statistical differences were found between sapwood and heartwood of *Acokanthera friesiorum* (Murichu) (p=0.0017) and for *P. serotina* (p=0.0121). By species, the volatile contents were significantly higher in *the Olea africana* and *M. juergensenii* 82.61 and 83.66%, respectively. A high emission of volatiles in combustion leads to deterioration of air quality and contributes to the generation of pollutants that can have negative repercussions on ecosystems and even on human health (Querol 2008).

In the volatile matter of charcoal, no statistical differences were found by type of wood (sapwood-heartwood) (p> 0.05) (Table 4.4). Volatile matter range was from 27.28 to 34.9% with an average of 31.27%. However, when making a general comparison between the volatile material of wood and charcoal, an increase of 158.6% of volatile was observed in wood combustion compared to charcoal of the five species.

In the present study, in relation to the percentage of volatile content, a charcoal of *Acokanthera friesiorum* (Murichu) and *Acokanthera friesiorum* (Murichu) presents an advantage from the energy point of view, since its combustion is slower and cleaner. On the other hand, the content of volatiles in charcoal of *the Olea africana*, White witch hazel and *Euclea divinorum* (Mikinyui) could increase the ignition ease and the speed of combustion. However, these samples would cause the liberation of tars and emission of fume (Bustamante-García et al. 2014). High amounts of volatile matter indicate that a heterogeneous carbonization process is carried out at low temperatures (Siddique 2008).

Table 4.17: Volatile Content of Tree Species

Tree Species		**Volatile Matter (%)**	
		Wood	**Charcoal**
Olea africana	Sapwood	82.08 (0.77)**a**	32.56 (0.82)**a**
	Heartwood	83.15 (0.53)**a**	32.72 (1.94)**a**
	Average	82.61 (0.84)**C**	32.64 (1.42)**B**
Acacia sp,	Sapwood	80.71 (1.66)**a**	28.16 (4.01)**a**
	Heartwood	80.71 (1.49)**a**	28.63 (1.16)**a**
	Average	80.71 (1.50)**B**	28.40 (2.82)**A**
Trichocladus ellipticus	Sapwood	84.08 (2. 21)**a**	34.90 (1.54)**a**
White witch hazel	Heartwood	83. 24 (1.82)**a**	33.59 (5.61)**a**
	Average	83.66 (1.98)**C**	34.25 (3.98)**B**
Euclea divinorum (Mikinyui)	Sapwood	79.17 (2.19)**a**	31.03 (2.90)**a**
	Heartwood	75.41 (4.07)**b**	34.09 (1.99)**a**
	Average	77. 29 (3. 69) **A**	32.56 (2.86)**B**
Acokanthera friesiorum	Sapwood	81.51 (1.10)**a**	27. 28 (1.16) **a**
(Murichu)	Heartwood	78.56 (1.40)**b**	29.72 (1. 23)**a**
	Average	80.03 (1.96)**B**	28.50 (1.71)**A**

Values in parentheses represent the standard deviation. Equal upper case letters in each column represent statistical equality per species (p=0.05). Equal lower case letters in each column represent statistical equality between sapwood and heartwood within each species (p=0.05)

Tree Species and Ash Content

The results in Table 4.18 show the ash content of the five tree species used for charcoal making in western Mau forest. The ash content fluctuates within the reported interval for sapwood and hardwoods from the state of Michoacán, Mexico (0.25-3.54%) and also for heartwood (0.22-2.10%) (MartínezPérez et al. 2015). With the exception of *Euclea divinorum* (Mikinyui), ash results are within the interval (0.10-1.0%) mentioned in the literature for temperate hardwoods (Fengel & Wegener 2003).

The ash content is an important parameter to consider for the selection of a biomass fuel. Under this criterion the wood of *Euclea divinorum* (Mikinyui) could be considered as of better quality. Conversely, high ash content causes problems because its accumulation obstructs the flow of combustion gases inside biomass boilers (Werkelin et al. 2011) as well as causing corrosion, erosion and abrasion (Melissari 2012).

Table 4. 18: Ash Content in Wood and Charcoal of Five Tree Species

Tree Species		Ash Content	
		Wood	**Charcoal**
Olea africana	Sapwood	0.63 (0.04)**a**	2.29 (0.11)**a**
	Heartwood	0.62 (0.06)**a**	2.10 (0.08)**a**
	Average	0.62 (0.05)**a**,**B**	2.19 (0.14)**B**
Acacia sp,	Sapwood	0.62 (0.09)**a**	1.09 (0.22)**a**
	Heartwood	0.50 (0.08)**a**	1.68 (0.32)**a**
	Average	0.56 (0.10)**A**	1.38 (0.41)**A**
Trichocladus ellipticus	Sapwood	0.87 (0.06)**a**	2.29 (0.12)**a**
White witch hazel	Heartwood	0.72 (0.07)**b**	2.30 (0.00)**a**
	Average	0.79 (0.10)**C**	2.29 (0.08)**B**
Euclea divinorum (Mikinyui)	Sapwood	1.56 (0.24)**a**	4.98 (1.02)**a**
	Heartwood	1.44 (0.15)**a**	4.68 (1.27)**a**
	Average	1.50 (0.19)**D**	4.83 (1.11)**C**
Acokanthera friesiorum	Sapwood	0.73 (0.14)**a**	1.06 (0.06)**a**
(Murichu)	Heartwood	0.63 (0.05)**a**	1.20 (0.00)**a**
	Average	0.68 (0.11)B	1.13 (0.08)**A**

Values in parentheses represent the standard deviation. Equal upper case letters in each column represent statistical equality per species (p=0.05). Equal lower case letters in each column represent statistical equality between sapwood and heartwood within each species (p=0.05)

Tree Species and fixed Carbon

The fixed carbon for the five tree species was determined and the results are summarized in Table 4.19.

Table 4.19: Tree Species and Fixed Carbon

Tree Species		Fixed Carbon	
		Wood	**Charcoal**
Olea africana	Sapwood	17.29 (0.78)**a**	65.15 (0.91)**a**
	Heartwood	16.24 (0.51)**a**	65.18 (1.99)**a**
	Average	16.76 (0.83)**A**	65.16 (1.48)**B**
Acacia sp,	Sapwood	18.68 (1.64)**a**	70.75 (4.23)**a**
	Heartwood	18.80 (1.48)**a**	69.69 (1.45)**a**
	Average	18.74 (1.49)**B**	70.22 (3.07)**C**
Trichocladus ellipticus White witch hazel	Sapwood	15.05 (2.19)**a**	62.81 (1.67)**a**
	Heartwood	16.04 (1.86)**a**	64.11 (5.62)**a**
	Average	15.55 (2.00)**A**	63.46 (4.00)**A,B**
Euclea divinorum (Mikinyui)	Sapwood	19.27 (2.17)**a**	63.99 (3.49)**a**
	Heartwood	23.15 (3.98)**b**	61.23 (1.30)**a**
	Average	21.21 (3.67)**C**	62.61 (2.89)**A**
Acokanthera friesiorum (Murichu)	Sapwood	17.76 (1.08)**a**	71.66 (1.18)**a**
	Heartwood	20.82 (1.38)**b**	69.08 (1.23)**a**
	Average	19.29 (1.99)**B**	70.36 (1.77)**C**

Values in parentheses represent the standard deviation. Equal upper case letters in each column represent statistical equality per species (p=0.05). Equal lower case letters in each column represent statistical equality between sapwood and heartwood within each species (p=0.05)

Fixed carbon (FC) of *Euclea divinorum* (Mikinyui) was significantly higher than that of the other species. However, the preference of people in the use of firewood species is related to attributes and characteristics such as the availability of timber resources as well as economic and energy implications (Aguirre-Cortés et al. 2018). Ruiz-Aquino et al. (2015) conducted a study in the same area and reported 14.7% and 16.5% of fixed carbon for *Q. laurina* and *Q. crassifolia*, respectively, and emphasize the importance of two species as good fuels in the study area.

In relation to the FC of charcoal, no differences were found by type of wood (sapwood and heartwood) (Table 4.19). However, when comparing the FC content of wood and charcoal, it was observed that FC content increases to 262% in compared to wood. Fixed carbon is related to volatile material, and it is possible to increase it to meet with international standards to 75% (NBN M11-001: 1984), 78% (DIN 1749:1989) and 75% (EN 1860-2:2005) if the process of charcoal elaboration is controlled (e.g. process of carbonization is controlled by the temperature inside the kiln) (Márquez-Montesino et al. 2001, Carrillo-Parra et al. 2013).

4.7 Influence of Wood Harvesting Techniques on the Quantity of Charcoal Production

The fourth objective was to evaluate effects of tree harvesting methods on quantity of charcoal production. Wood harvesting is the preparation of logs in a forest or a tree plantation. This includes cutting of trees, their conversion into logs and arrangement of the logs in the kiln for carbonization. This section reports and discusses all aspects that affect wood harvesting in terms of charcoal quantity. These sections include: (i) Tools used in wood harvesting.

4.7.1 Tools Used in Wood Harvesting

The study sought to establish the kind of tools used during wood harvesting. The results are shown in Table 4.20.

Table 4.20: Charcoal Producers' response on Tools used in Wood Harvesting

Tools Used	**Frequency**	**Percent (%)**
Handheld tools		
"Panga"/machete	96	31
"Jembe"/ hoe	74	24
Spade	65	21
Axe	47	15
Pitchfork	9	3
Machine / Powered Tool		
Power saw	19	6
Total	**310**	**100**

In view of Table 4.20, 96 (31%) of the respondents indicated that they used *"Panga"*/machete, 74 (24%) indicated they used *"Jembe"/* hoe, 65 (21%) indicated they used spade, 47 (15%) indicated while a few 19 (6%) used power saw. The study reveals that simple tools are most common for wood harvesting than machinery tools like the power saw. The machete which is the most common tool used in wood harvesting by the producers. This can be attributed to the location of wood harvesting being the government forest, which means it is "illegal" to produce charcoal there. Hence the need to be as silent as possible to not attract authorities to the production site. The power saw is least used as it is expensive and very noisy. These tools affect the quantity of charcoal in terms of how many trees are cut to produce charcoal. Since machete and axe are commonly used to cut down trees.

Table 4.21: Chi-Square on Number of Logs and Charcoal Quantity

Number of Logs	n	%	Chi-Square (χ^2)	p
Less than 50	18	18	1.544	0.006
Between 51 – 90	76	76		
Over 91	6	6		

Seventy six percent (76%) of the respondents indicated that 51 -90 logs produced preferred charcoal quantity. The chi-square statistic indicates statistically significant relationship between number of logs [χ^2=1.544, $p<0.05$] and quantity of charcoal. This could be attributed to efficiency in conversion of wood to charcoal where logs are ranging from 51 to 90, however, the result was determined by the size of the kiln being used.

4.8 Influence of Carbonization Technique on Quality of Charcoal Produced

The fifth objective was to determine the effects of earth mound kiln on quality of charcoal prodcution. The traditional earth mound kiln was used by all the respondents interviewed. Reasons being that it is simple to build, and the material used is affordable.

The other benefit is that it can be built whenever the material is found to reduce transportation since production does take place in the government forest. This section includes (i) Respondents that dry wood. (ii) how long they dry the wood.

4.8.1 Producers that Dry Wood before Carbonization

The drying of wood before carbonization has an influence on the quality and quantity of charcoal produced, the producers were asked whether they dry their wood before the carbonation, the results are presented in Table 4.22.

Table 4.22: Response on Dry Wood before Carbonization

Drying of Wood	Frequency	Percent
Do not dry wood	19	70
Dry wood	8	30
Total	**27**	**100**

The results in Table 4.22, 19 (70%) of the respondents indicated that they did not dry wood before carbonization process. The respondents cited inadequate time to allow them to dry the wood since the production site was in the government forest hence considered “illegal”. They wanted to maximize the little time they have to produce the charcoal and leave the forest for fear of being caught. However, a few 8 (30%) dried the wood before carbonization process.

4.8.2 Period of Drying Wood

The study sought to establish the length in time they dried the wood before carbonization. The results are shown in Table 4.23.

Table 4.23: Periods of Drying Wood before Carbonization

Period taken to Dry Wood (Days)	Frequency	%
7	230	74
5	40	13
14	40	13
Total	**310**	**100**

The results indicated that majority 230 (74 %) of the respondents dried wood before carbonization for seven days. Although, this period is not enough to get seasoned wood for carbonization. For seasoned wood to be achieved, it can take up to 2-4 months (Chiteculo et al., 2018).

4.8.3 Moisture of wood

The moisture content in the wood has an impact on charcoal production, as the moisture interferes with the carbonization process, which means the quality at the end is compromised. The moisture in the wood has all to be driven off as vapor before carbonization can take place. To evaporate water requires a lot of energy so that using the sun to pre-dry the wood as much as possible before carbonization greatly improves efficiency.

Table 4.24: Correlation Analysis of Number of days taken to Dry Wood and Moisture of Wood

Correlation	Wood Moisture
Number of days	0.564
p	0.001
n	310

The results in Table 4.24 indicated that there was a positive and significant relationship between the number of days taken to dry wood and moisture of wood. This implies that an increase in number of days taken to dry wood increased the reduction of moisture level in woods that results to production of quality charcoal with little or no smoke.

The study revealed that traditional kiln was the main method used to produce charcoal in the study areas. Those who mentioned that they dry the wood before carbonization, do it in a period of 7 days (Njoroge, 2013), which isn't enough as 2 to 4 months is needed to season the wood well.

4.8.4 Influence of Carbonization Techniques on the Quality of Charcoal Produced

Moisture content in the Material making the Charcoal

The moisture content of the material making charcoal was determined for the different carbonization techniques (drum, metal and traditional earth mound) for three sizes of the billets used (large, medium and small) and the results are shown in Table 4.25.

Table 4.25: Effect of Kiln Type and Billets Size on Charcoal Moisture Content (%)

	Billets Sizes		
Kiln Type	**Large**	**Medium**	**Small**
Drum	-	-	0.482 A
	a	a	a
Metal	1.165A	1.341 A	1.125 A
	a	a	a
Traditional	0.167 B	0.351 B	1.108 B

In the same column, means with the same upper case letter are not significantly different (p=0.05). In the same row, means with the same lower case letter are not significantly different (p=0.05)

Charcoal moisture content of the samples varied between 0.07 and 2.41%. These values are in line with the average moisture content of charcoal (1%) fresh from an open kiln, although charcoal can absorb moisture with time to up to 5-10% FAO (1987), and this is in line of the findings of Nasroun (1985), who reported a value of 2.99%

There were no significant differences between all billet sizes in metal and traditional kilns (Table 4.20). There were no significant differences in charcoal moisture content between kiln types for the small billets. However, the metal kiln had significantly higher moisture content than the traditional kiln for the large and medium size billets. The relatively low values found in this study for the *Olea Africana* charcoal (Table 4.25) is an indication for good quality because high moisture content values reduces the heating values of fuels.

Volatile Content

The volatile content of the samples ranged between 5.03 and 33.52 %. For each of the billet sizes, there were significant differences between the kiln types; the metal kiln had the highest values, which ranged between 20 and 32 (Table 4.21) and they were lower than the value (50%) reported by Nasroun (1985) for the charcoal produced by metal kiln.

Significant differences were also found between the three billet sizes. At each of the three kilns; the small billets had significantly the highest amount while the large billets had the lowest amount of volatile matter. The volatile matter other than water in charcoal comprises all those liquids and tarry residues not fully driven off in the process of carbonization The traditional kiln had the lowest average values (5.2 to 12.4%) for all billet sizes and these are within the lower tail of the range of volatile matter known for charcoal (FAO, 1987 Such low values indicate that the carbonization time was longer and temperature was higher in the traditional kiln than in the other two kilns types.

Table 4.26: Effect of kiln type and billets size on charcoal volatile content (%)

	Billet Size		
Kiln Type	**Large**	**Medium**	**Small**
Drum	-	-	17.402 B
	c	b	A
Metal	20.665 A	28.923 A	32.102 A
	c	b	A
Traditional	5.219 B	10.382 B	12.472 B

In the same column, means with the same upper case letter are not significantly different (p=0.05). In the same row, means with the same lower case letter are not significantly different (p=0.05)

Fixed Carbon

The magnitude of the fixed carbon content of the samples ranged between 61.97 and 89.94%. There were significant differences between the kiln types. The large and medium size billets of the traditional kiln had significantly greater carbon content (82.8-89.7%) than those of the metal kiln. The highest values for the small billets (82.7) were also found in traditional kiln followed by drum kiln (Table 4.22). FAO (1987) reported that the fixed carbon content of charcoal ranges from a low of about 50% to a high or around 95%. However, Jarvis (1960) noted that good quality.

Industrial charcoal has a fixed carbon content of 75 to 82 percent and the values found for charcoal produced from all billet sizes in the traditional kiln were higher than this range. The three billet sizes were significantly different from each other in the metal kiln. Large billets had significantly the highest while small billets had the lowest carbon content. Nasroun (1985) found lower value for fixed carbon 44.33 for the metal kiln.

Table 4.27: Effect of Kiln Type and Billets Size on Charcoal Fixed Content (%)

	Billet Size		
Kiln Type	**Large**	**Medium**	**Small**
Drum	-	-	77.439 B
	a	b	c
Metal	73.699 B	66.971 B	63.640 A
	a	b	c
Traditional	89.661 A	82.844 A	82.712 A

In the same column, means with the same upper case letter are not significantly different (p=0.05). In the same row, means with the same lower case letter are not significantly different (p=0.05)

Ash Content

The maximum and minimum ash content values of the samples were 3.97 and 6.79, respectively. These values were in line with the range given by FAO (1987) for various species. The result of Nasron (1985) showed a lower percentage of ash content for metal kiln. There were no significant differences between the medium and small billets of the metal kiln and they had significantly the lower values. In the traditional kiln, the medium billets had the highest while the small ones had the lowest ash content with significant differences between the three sizes (Table 4.28). Significant differences were found between kiln types for the medium and small billets, but not for the large ones. The lower values were associated with the metal kiln for the medium and small billets.

Table 4.28: Effect of Kiln Type and Billets Size on Charcoal Ash Content (%)

	Billet Sizes		
Kiln Type	**Large**	**Medium**	**Small**
Drum	-	-	5.159 A
	a	b	b
Metal	5.636 A	4.106	4.258 B
	b	a	c
Traditional	5.120 A	6.775 A	4.816 A

In the same column, means with the same upper case letter are not significantly different (p=0.05). In the same row, means with the same lower case letter are not significantly different (p=0.05)

4.9 Influence of Carbonization Technique on Quantity of Charcoal Produced

The sixth objective was to determine effects of earth mound kiln on quantity of charcoal production. The effect of earth mound kiln on quantity of charcoal was assessed. The mean size of a kiln in the study area was 10 m long, 3 m wide and 2m high. Such a kiln contained a mean number of 100 logs cut into 2.5 meters long pieces each. Given a mean number of ten (10) logs obtained from one medium to large sized tree (Girth $\geq$ 30 cm) each kiln required 10 trees. This section includes: (i) the number of bags produced from the kilns.

4.9.1 Number of Bags Produced and Size of the Kilns

The study sought to establish the relationship between number of bags produced per kiln and Kiln size. The results are as shown in Table 4.29.

Table 4.30: Correlation Analysis of Number of Bags and Size of Kiln

	Size of Kiln
Number of bags	0.612
p	0.004
n	310

The results in Table 4.30 indicated that there was a strong, positive and significant relationship between number of bags produced and size of the Kilns. This implies that an increase in size of the kiln lead to an increase in number of bags of charcoal produced. This is because the larger the size of the kiln the more logs can be carbonized and hence the yield.

4.9.2 Influence of Carbonization Technique on the Quantity of the Charcoal produced

A comparison was made to compare the conversion rates of three techniques used in charcoal production. The techniques compared were traditional earth mound, the drum and the metal kilns. The results are summarized in Table 4.31.

Table 4.31: Average Charcoal Yield by Type of Kiln Used

Kiln Type	Weight of wood (Kg)	Weight of charcoal (Kg)	Number of sacks (Each of 37 kg)	Conversion ratio
Drum	83.9	20.6	0.56	24.9%
Metal	5843.2	1286.8	34.8	22.0%
Traditional	2443.5	501.0	13.5	20.5

The conversion ratio of drum kiln (24.9%) was the highest followed by that of the metal kiln (22%) and the traditional kiln (20.5%). The yield of the metal kiln was less than that

(31%) reported by Nasroun (1985), and this might be due to the high volatile matter of the previous experiment.

The capacity of the drum was 0.092 m of stacked volume of small billet size. For the metal kiln it was 3.5, 3.5 and 3.25 m^3 for the large, medium and small size billets, and the weight of the produced charcoal was 468.6, 460.4 and 357.9 kg, respectively (Table 4.32). The capacity of the traditional kilns was variable. The number of sacks was calculated according to the average commercial weight, which is 37 kg of charcoal per sack.

Table 4.32: Charcoal Yield (Kg) and Number of Sacks Produced By Kiln Type and Billet Size

	Billet Size		
Kiln Type	**Large**	**Medium**	**Small**
Drum	-	-	20.9 (0.56 sacks)
Metal	468.6 (12.66 sacks)	460.4 (12.44 sacks)	357.9 (9.670 sacks)
Traditional	192.3 (5.19 sacks)	111.1 (3.003 sacks)	197.8 (5.345 sacks)

There is indication that conversion ratio was highest for the small billets followed by the medium and then the large billets. The average conversion ratio (%) was 20.4-18.6 for the large billets, 22.2-21.4 for the medium billets and 24.2 - 22.2-24.9 for the small billets (Table 4.33).

Table 4.33: Average Conversion Ratio by Kiln Type and Billet Size

	Billet Size		
Kiln Type	**Large**	**Medium**	**Small**
Drum	-	-	24.9
Metal	20.4	22.2	24.2
Traditional/Earth Mound	18.6	21.4	22.2

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the discussion, summary of findings, conclusions and recommendations.

5.2 Summary of Study Findings

The following is the summary of findings:

(i) Simple tools like machete and axe were commonly for tree harvests. The power saw is not commonly used due to its noisiness and the cost of acquisition.

(ii) Preferred girth of tree cut ranged between 15-30 cm as they produced good quality of charcoal. Majority of the producers had less than 10 years of experience in the business. A chi-square test of years of experience and preferred girth of cut trees revealed that there existed no significant relationship between these two variables, as years of experience did not determine the girth of tree to be cut for charcoal production.

(iii) Majority of producers used earth mound kiln because the kiln was simple to build, and the materials used were easily available and affordable.

(iv) Majority of producers did not dry the wood before carbonization process. Those who dried the wood before carbonization dried the wood for a period of 7 days.

(v) It was established that there was a moderate, positive and significant relationship between number of days taken to dry wood and moisture of wood. This implied that an increase in number of days taken to dry wood increased the reduction of moisture level in woods that results to production of quality charcoal with little or no smoke.

(vi) Majority of producers perceive that indigenous species produces best charcoal, but in reality, the majority go for exotic species exclusively, others do a mix of the indigenous and exotic species. The most preferred species are *Acacia lahai* and *Eucalyptus ficifolia*.

(vii) Charcoal producers preferred using deadwood branches to produce charcoal. A *t* – Test was carried, and the dry season was associated with a statistically significantly larger mean of number of charcoal bags produced than the dry season. Also, another *t*-Test was done for species and seasons and results show that in both seasons, that there is no significant statistical difference in the means of charcoal bags produced from exotic species and indigenous species.

5.3 Discussions

The section of the thesis is a discussion of the findings of the study as per the objectives stated in section 1.5.

5.3.1 Socio-economic characteristics of the Respondents

The level of formal education is low among the respondents, this was indicated by the low progression rate to secondary schools, only (17.1 %) progress to secondary schools, leaving 77.4 % to seek employment in business and charcoal production to sustain themselves and their families (Ndegwa, Anhuf, Nehren, Ghilardi & Iiyama, 2016), as other jobs are hard to find.

The majority of the men were involved in charcoal production, while only a few women were involved in selling charcoal at market centres, this is due to the cultural element that charcoal burning is a man's work but the trend and believes are changing so that a significant number of females have taken up charcoal burning as a coping strategy. These findings concur with Kyengo (1998) findings that showed that majority of actors in charcoal business were male, still showing that the, charcoal burning was a man's job since he is the head of the household and he has responsibility to feed his people. The upcoming trend whereby females are getting involved in charcoal burning could be attributed to female headed households.

The youth (under 30 years) participate less than the adults aged between (30-40years) in the charcoal value chain, as they find the job too tedious with too many risks and profits are not guaranteed. They move to the cities to look for office jobs or other forms of employment. The adults in the age bracket between 30 and 40 years were more likely to participate in charcoal production the most because they have families to provide for and it was the easier option for them since they did not have the high-level education to qualify for office jobs. This findings are in line with Kyengo (1998) findings that established that adults in the age bracket between 30 and 40 years were more likely to participate the most because they have families to provide for and it was the easier option for them since they did not have the high-level education to qualify for office jobs.

The study found that many ethnic communities lived in the study area adjacent to the western Mau forest. This led to the conclusion that Kericho County is ethnically diverse. This can be attributed to migration to Kericho County for better life in terms of farming opportunities as a result of the land being fertile and also the weather is conducive for agriculture all year round (Kiruki, van der Zanden, Kariuki & Verburg, 2019).

5.3.2 Influence of Tree Species Utilized on the Quality of the Charcoal Produced

The quality of charcoal is influenced by the type of tree species that is used to make the charcoal. Indigenous tree species were found to produce charcoal of higher quality than the exotic trees. The indigenous tree species utilized by the participants in western Mau forest included *Olea africana*, *Acokanthera friesiorum*, *Acacia seyal*, *Acacia lahai* and *Euclea divinorum*. The exotic tree species utilized included *Eucalyptus saligna*, *Eucalyptus ficifolia*, *Grevillea robusta*, and *Cupressus lusitanica*. This is due to quality of charcoal produced from indigenous species is of more superior quality, in terms of burning which lasts longer than the one made from exotic species (Adeniji, Zaccheaus, Ojo, & Adedeji, 2015).

This selectivity of tree girths of 15-30cm tends to lead to destruction of the forests as particular species tend to be targeted for cutting. A study on charcoal production through selective logging revealed that selective logging leads to degradation which is manifested through reduction of preferred species (Ndegwa et al., 2016) . This is when the producer selects trees according to species preference and girth. In specific, the study found the most important effect of the production of charcoal on the accessible trees, which has a high density of the preferred tree species in large sizes. The selective logging affects charcoal quality as it depends on the species readily available and as seen from the surveys, a mix of species is what is common in order to supply demand which means quality can be compromised but quantity demand is met.

Acacia species are most preferred despite the ban. Kenya Forest Service and the Kenya Charcoal Regulations prohibit the use of *Santalum paniculatum* (sandal wood) and *Acacia* species in charcoal production except in special cases, where permit must be obtained from KFS (KFS, 2013).

A study on assessing effect of charcoal production in Kenya mentioned that charcoal users preferred *Acacia* species because it produces strong heat and lasts longer and it produces less ash (Oduor, Ngugi, & wa Gathui, 2012). According to them they buy what is available because they know it will still serve the purpose for cooking and heating. They seem not to think that charcoal from particular tree species may produce more heat or produce less smoke or more ash (Onekon & Oscar, 2016). This shows that species is an important factor in determination of quality of charcoal.

The comparison test of means of moisture content between species indicates: *the Olea africana* was statistically lower to the rest of species. Based on the moisture content, *the Olea africana* is more efficient as a fuel, because the net calorific value increases with lower moisture content. In all studied species, the moisture content was less than 5%.

On average, the volatile content for sapwood and heartwood of the five species was 80.86%. It has been reported that species with less volatile content are better as fuels because they promote cleaner combustion (Heya et al. 2014). By wood type, statistical differences were found between sapwood and heartwood of the *Olea africana,* the acacia sp, White witch hazel, *Euclea divinorum* (Mikinyui) and *Acokanthera friesiorum* (Murichu) ($p=0.0017$) and for *Acokanthera friesiorum* (Murichu) ($p=0.0121$). By species, the volatile contents were significantly higher in *the Olea africana* and White witch hazel 82.61 and 83.66%, respectively. A high emission of volatiles in combustion leads to deterioration of air quality and contributes to the generation of pollutants that can have negative repercussions on ecosystems and even on human health (Querol 2008).

In the volatile matter of charcoal, no statistical differences were found by type of wood (sapwood-heartwood) ($p > 0.05$). Volatile matter range was from 27.28 to 34.9% with an average of 31.27%. However, when making a general comparison between the volatile material of wood and charcoal, an increase of 158.6% of volatile was observed in wood combustion compared to charcoal of the five species.

Regarding the ash content, it was established that ash content fluctuated within the reported interval for sapwood hardwoods (0.25-3.54%) and also for heartwood (0.22-2.10%) (MartínezPérez et al. 2015). With the exception of *Euclea divinorum* (Mikinyui), ash results are within the interval (0.10-1.0%) mentioned in the literature for temperate hardwoods (Fengel and Wegener 2003). The ash content is an important parameter to consider for the selection of a biomass fuel. Under this criterion the wood of *Euclea divinorum* (Mikinyui) could be considered as of better quality. Conversely, high ash content causes problems because its accumulation obstructs the f low of combustion gases inside biomass boilers (Werkelin et al. 2011) as well as causing corrosion, erosion and abrasion (Melissari 2012).

Regarding Fixed carbon, the study established that (FC) of *Euclea divinorum* (Mikinyui) was significantly higher than that of the other species. However, the preference of people in the use of firewood species is related to attributes and characteristics such as the availability of timber resources as well as economic and energy implications (Aguirre-Cortés et al. 2018). Ruiz-Aquino et al. (2015) conducted a study in the same area and reported 14.7% and 16.5% of fixed carbon for *Q. laurina* and *Q. crassifolia*, respectively, and emphasize the importance of two species as good fuels in the study area.

In relation to the FC of charcoal, no differences were found by type of wood (sapwood and heartwood). However, when comparing the FC content of wood and charcoal, it was observed that FC content increases to 262% in compared to wood. Fixed carbon is related to volatile material, and it is possible to increase it to meet with international standards to 75% (NBN M11-001: 1984), 78% (DIN 1749:1989) and 75% (EN 1860-2:2005) if the process of charcoal elaboration is controlled (e.g. process of carbonization is controlled by the temperature inside the kiln) (Márquez-Montesino et al. 2001, Carrillo-Parra et al. 2013).

5.3.3 Influence of Tree Species Utilized on the Quantity of Charcoal Produced

The findings of the study indicate that the type of species used could influence the quantity of charcoal that is produced in western Mau forest. The study found that *Olea africanum* made best quality charcoal and therefore was mostly preferred. However, due to scarcity of the *Olea africana*, some charcoal burners preferred putting a mix of some selected good species which also gave good quality charcoal. These tree species included;

the *Olea africana,* the *Acacia* sp, White witch hazel, *Euclea divinorum* (Mikinyui) and *Acokanthera friesiorum* (Murichu). From experimental tests results, the highest yield of charcoal was obtained with wood of *Olea africanum*. This species was statistically superior to the others (the *Olea africana*, the acacia sp, White witch hazel, *Euclea divinorum* (Mikinyui) and *Acokanthera friesiorum* (Murichu).

5.3.4 Influence of Tree Harvesting Techniques on the Quality of the Charcoal Produced

The findings of the study indicate that the tools used in harvesting the trees determine the quantity of the charcoal produced in western Mau forest. The power saw, which is able to harvest many trees within a short period was rarely used due to the noise it makes and is able to attract the forest guards. The tools normally used to cut the trees by the producers are the axe and *panga* which are hand tools that cannot cut many trees within a short period. These tools affect the quantity of charcoal in terms of how many trees are cut to produce charcoal. Since machete and axe are commonly used to cut down trees. Smaller trees are chosen since the tools can't handle cutting big trees (Alfaro & Jones, 2018). This is also for easier conversion to logs when cutting medium to small trees. Power saw is the least popular option for cutting trees as mentioned before, but in cutting trees and conversion to logs is most efficient.

5.3.5 Influence of Harvesting Techniques on the Quantity of the Charcoal Produced

This could be attributed to efficiency in conversion of wood to charcoal where logs are ranging from 51 to 90, however, the result was determined by the size of the kiln being used.

The study revealed that simple tools were used to harvest wood such as axe and machete. Tools like the power saw was seldom used due to their noisiness and expensive to acquire (Kyengo, 1998). The producers illegally collect wood from government forest, hence the choice of tools. However, for fear of legal repercussions and threats to their livelihoods, charcoal producers may be afraid to disclose the actual sources of wood, and thus such reports on wood sources used for charcoal production need to be viewed with caution as they may confuse efforts to manage natural resources.(Njenga et al., 2013).

Charcoal moisture content of the samples varied between 0.07 and 2.41%. These values were in line with the average moisture content of charcoal (1%) fresh from an open kiln, although charcoal can absorb moisture with time to up to 5-10% FAO (1987), and this is in line of the findings of Nasroun (1985), who reported a value of 2.99%

There were no significant differences between all billet sizes in metal and traditional kilns. There were no significant differences in charcoal moisture content between kiln types for the small billets. However, the metal kiln had significantly higher moisture content than the traditional kiln for the large and medium size billets. The relatively low values found in this study for the Olea Africana charcoal is an indication for good quality because high moisture content values reduces the heating values of fuels.

The volatile content of the samples ranged between 5.03 and 33.52 %. For each of the billet sizes, there were significant differences between the kiln types; the metal kiln had the highest values, which ranged between 20 and 32 and they were lower than the value (50%) reported by Nasroun (1985) for the charcoal produced by metal kiln.

Significant differences were also found between the three billet sizes. At each of the three kilns; the small billets had significantly the highest amount while the large billets had the lowest amount of volatile matter. The volatile matter other than water in charcoal comprises all those liquids and tarry residues not fully driven off in the process of carbonization The traditional kiln had the lowest average values (5.2 12.4%) for all billet sizes and these are within the lower tail of the range of volatile matter known for charcoal (FAO, 1987 Such low values indicate that the carbonization time was longer and temperature was higher in the traditional kiln than in the other two kilns types.

The magnitude of the fixed carbon content of the samples ranged between 61.97 and 89.94%. There were significant differences between the kiln types. The large and medium size billets of the traditional kiln had significantly greater carbon content (82.8-89.7%) than those of the metal kiln. The highest values for the small billets (82.7) were also found in traditional kiln followed by drum kiln. FAO (1987) reported that the fixed carbon content of charcoal ranges from a low of about 50% to a high or around 95%. However, Jarvis (1960) noted that good quality.

Industrial charcoal has a fixed carbon content of 75 to 82 percent and the values found for charcoal produced from all billet sizes in the traditional kiln were higher than this range. The three billet sizes were significantly different from each other in the metal kiln. Large billets had significantly the highest while small billets had the lowest carbon content. Nasroun (1985) found lower value for fixed carbon 44.33 for the metal kiln.

The maximum and minimum ash content values of the samples were 3.97 and 6.79, respectively. These values were in line with the range given by FAO (1987) for various species. The result of Nasron (1985) showed a lower percentage of ash content for metal kiln. There were no significant differences between the medium and small billets of the metal kiln and they had significantly the lower values. In the traditional kiln, the medium billets had the highest while the small ones had the lowest ash content with significant differences between the three sizes. Significant differences were found between kiln types for the medium and small billets, but not for the large ones. The lower values were associated with the metal kiln for the medium and small billets.

5.3.6 Influence of Carbonization Techniques on the Quality of Charcoal Produced

The findings of the study indicated that the majority of charcoal producers in western Mau forest used three (3) techniques to achieve the carbonation process, this include the traditional earth mound technique, the metal kiln and the drum kiln techniques. The quality of charcoal produced varies with the technique used in the carbonization process.

The carbonization process is also affected by the dryness of the wood used to make charcoal. Green or wet wood tends to produce very little charcoal and lots of smoke (Pereira, Martins, Pecenka and Angélica de Cássia, 2017). Previous studies on efficiency of kilns mention that dry wood increases the efficiency of kiln to produce quality charcoal. Control of the carbonization process is not always easy in most cases, however, and often results in low-grade charcoal contaminated with soil crumbs (Schure, Pinta, Cerutti, & Muvatsi, 2019). The traditional earth mound kiln technique of carbonation allows a lot of air to enter the kiln and this slows the process and causes the charcoal burn completely reducing the quality of the charcoal produced.

5.3.7 Influence of Carbonization Techniques on the Quantity of Charcoal Produced

The study found that the technique used in the carbonization process affects the quantity and quality of charcoal produced. However, the findings disagree with Shikorire (2015) findings that indicated that an increase in earth mound kiln size led to reduced charcoal yield as a result of increased inefficiency during carbonization. The study revealed that the kilns sampled in the study areas produced 1-7 bags of charcoal per operation (Nahayo, Ekise, & Mukarugwiza, 2013). Due to inefficiency of this method, less amount of charcoal is produced, and of low quality. When it comes to the use of traditional kilns in the study, the data collected shows the importance of coupling technical solutions with wider capacity and awareness needs and promoting an enabling framework for charcoal production. The importance of charcoal makers' capacities and skills need to be locally appropriate, acceptable to producers and need to be linked to training and education (Schure et al., 2019). Awareness for alternative charcoal technologies is not only needed at the level of production, but also at the level of retail and consumption and among state agencies at different levels to support this. Producers are forced to work in uncertain and ambiguous circumstances, which is likely to have them construct kilns in quick and inefficient manners instead of investing in improved practices and taking time for drying of the wood and frequent monitoring of the carbonization process.

5.4 Conclusions of the Study

The potential benefits of a regulated charcoal sector need to be accessed by better disseminating and then scaling up the Charcoal Rules implementation, but also by strengthening the capabilities of existing CPAs, speeding up KFS' registration process, and by adopting a thorough service extension approach, at least initially, before using policing and similar clamp-down approach which only make operators go even more underground (e.g. producing and transporting at night).

Extension support can result in reducing massive wastage during carbonization. This can also be achieved through partnerships with research organizations such as KEFRI to ensure that cheaper and user-friendly wood carbonization technologies are developed.

Better techniques are just one side of the coin, however. At the same time, operators along the value chain need entrepreneurial capacity building and should have business plans and adequate records for their operations. This also brings out the need of more in-depth charcoal trade research specific to the Mau region as a whole. Other areas like Kitui and Machakos where there is charcoal production, have tried to streamline their charcoal activities.

There is a need for charcoal producers to be trained on post-harvest management practices such as management of coppices, fertilization, and shoot or sucker protection to ensure improved recovery rates (Hosier, 1993). In parallel, investment in charcoal production centers with improved kiln technologies can be introduced to encourage formation of CPAs in the study areas. This will enhance the formalization of this process and ensure more efficient and sustainable ways of producing charcoal and reduce the pressure from the government forests.

Technical improvements, however, can only follow a less hypocritical political environment whereby banning and criminalizing rules and regulations continue to be adopted, while production and demand are maintained or keep growing. Only in such an environment, with politicians and decision makers putting the topic on top of their agenda. This will support livelihoods impacts but also encourage sustainable production and marketing systems for charcoal production.

5.5 Recommendations of the Study

(i) The charcoal producers should come together and form CPAs in order to have bargaining power and work together with CFAs in order to have an agreement on access of trees, including the terms and conditions.

(ii) The government and relevant organizations should facilitate forest plantations for charcoal production and fuel wood purposes. This will deter charcoal producers from going into the government forest to produce charcoal.

(iii) The charcoal producers should exploit the current best practices as regards the technology employed in the production activity. This will ensure that they have access to modes of production which guarantee them of the best quality charcoal and minimal wastage in the production activity and therefor increase their income.

(iv) The government and the county governance structures should ensure compliance with the statutory regulations governing the charcoal industry in the best manner possible and they should also make the regulations industry friendly.

5.6 Suggestions for Further Studies

Future research work is needed to study the potentiality of using small size billets produced by lopping mature forest trees for charcoal production and the potentiality of utilizing young, short-rotation forest trees from rotations including growth trend, management, production system involving local communities and productivity.

REFERENCES

Adeniji, O. A., Zacchaeus, O. S., Ojo, B. S., & Adedeji, A. S. (2015). Charcoal Production and Producers' Tree Species Preference in Borgu Local Government Area of Niger State, Nigeria. *Journal of Energy Technologies and Policy*, *5*(11), 1-8.

Baumert, S., Luz, A. C., Fisher, J., Vollmer, F., Ryan, C. M., Patenaude, G., & Macqueen, D. (2016). Charcoal supply chains from Mabalane to Maputo: Who benefits?. *Energy for Sustainable Development*, *33*, 129-138.

Bourque, C. P. A., Buchanan, W., & Hassan, Q. K. (2009). An analysis of habitat suitability and charcoal-yielding characteristics of five exotic tree species intended for bioenergy production in Jamaica. *Journal of Biobased Materials and Bioenergy*, *3*(1), 46-56.

Chiteculo, V., Lojka, B., Surový, P., Verner, V., Panagiotidis, D., & Woitsch, J. (2018). Value Chain of Charcoal Production and Implications for Forest Degradation: Case Study of Bié Province, Angola. *Environments*, *5*(11), 113.

Dam, J. V. (2017). The charcoal transition: greening the charcoal value chain to mitigate climate change and improve local livelihoods. *The charcoal transition: greening the charcoal value chain to mitigate climate change and improve local livelihoods.*

FAO (2016) Forestry for a low-carbon future: integrating forests and wood products in climate change strategies. *FAO Forestry Paper No. 177*. Rome.

Fuwape, J. A. (1996). Effects of carbonization temperature on charcoal from some tropical trees. *Bioresource technology*, *57*(1), 91-94.

Fuwape, J. A., & Akindele, S. O. (1997). Biomass yield and energy value of some fast-growing multipurpose trees in Nigeria. *Biomass and Bioenergy*, *12*(2), 101-106.

Ghaffariyan, M. R., & Brown, M. (2013). Selecting the efficient harvesting method using multiple-criteria analysis: A case study in south-west Western Australia. *Journal of Forest Science*, *59*(12), 479-486.

IEA (International Energy Agency), 2014. Africa Energy Outlook - World Energy Outlook Special Report - WEO2014_AfricaEnergyOutlook.pdf. OECD/IEA, Paris, France.

Kabisa, M., Mulenga, B. P., Ngoma, H., & Kandulu, M. M. (2020). *The Role of Policy and Institutions in Greening the Charcoal Value Chain in Zambia* (No. 1879-2020-472).

Kalaba, F. K., Quinn, C. H., Dougill, A. J., & Vinya, R. (2013). Floristic composition, species diversity and carbon storage in charcoal and agriculture fallows and management implications in Miombo woodlands of Zambia. *Forest Ecology and Management*, *304*, 99-109.

Khristova, P., & Khalifa, A. W. (1993). Carbonization of some fast-growing species in Sudan. *Applied energy*, *45*(4), 347-354.

Kimaryo, B. T., & Ngereza, K. I. (1989). Charcoal production in Tanzania: using improved traditional earth kilns. *Manuscript report/IDRC; 216e*.

Kiruki, H. M., van der Zanden, E. H., Gikuma-Njuru, P., & Verburg, P. H. (2017). The effect of charcoal production and other land uses on diversity, structure and regeneration of woodlands in a semi-arid area in Kenya. *Forest ecology and management*, *391*, 282-295.

Kiruki, H. M., van der Zanden, E. H., Kariuki, P., & Verburg, P. H. (2019). The contribution of charcoal production to rural livelihoods in a semi-arid area in Kenya. *Environment, Development and Sustainability*, 1-30.

Manavakun, N. (2014). *Harvesting operations in eucalyptus plantations in Thailand. Dissertationes Forestales 177* (Doctoral dissertation, Dissertation, University of Helsinki, Finland).

MEA (Millennium Ecosystem Assessment), 2005a. Millennium Ecosystem Assessment: Ecosystems and Human Wellbeing: Synthesis. Island Press, Washington DC, USA.

Ndegwa, G., Anhuf, D., Nehren, U., Ghilardi, A., & Iiyama, M. (2016). Charcoal contribution to wealth accumulation at different scales of production among the rural population of Mutomo District in Kenya. *Energy for Sustainable Development*, *33*, 167-175.

Ngulube, E. S. (2013). *Prediction of timber harvesting productivity for semi-mechanised systems in Viphya forest plantations, Malawi* (Doctoral dissertation, University of Pretoria).

Okello, B. D., O'connor, T. G., & Young, T. P. (2001). Growth, biomass estimates, and charcoal production of Acacia drepanolobium in Laikipia, Kenya. *Forest Ecology and management*, *142*(1-3), 143-153.

Okoko, A., Reinhard, J., von Dach, S. W., Zah, R., Kiteme, B., Owuor, S., & Ehrensperger, A. (2017). The carbon footprints of alternative value chains for biomass energy for cooking in Kenya and Tanzania. *Sustainable Energy Technologies and Assessments*, *22*, 124-133.

Okoko, A., Von Dach, S. W., Reinhard, J., Kiteme, B., & Owuor, S. (2018). Life Cycle Costing of Alternative Value Chains of Biomass Energy for Cooking in Kenya and Tanzania. *Journal of renewable energy*, *2018*.

Pluchon, N., Casetou, S. C., Kardol, P., Gundale, M. J., Nilsson, M. C., & Wardle, D. A. (2015). Influence of species identity and charring conditions on fire-derived charcoal traits. *Canadian Journal of Forest Research*, *45*(12), 1669-1675.

Ryan, C.M., Berry, N.J., Joshi, N., 2014. Quantifying the causes of deforestation and degradation and creating transparent REDD+ baselines: a method and case study from central Mozambique. *Appl. Geogr. 53*, 45–54.

Samojlik, T., Jędrzejewska, B., Michniewicz, M., Krasnodębski, D., Dulinicz, M., Olczak, H., & Rotherham, I. D. (2013). Tree species used for low-intensity production of charcoal and wood-tar in the 18th-century Białowieża Primeval Forest, Poland. *Phytocoenologia*, *43*(1-2), 1-12.

Schenkel, Y., Bertaux, P., Vanwijnbserghe, S., & Carre, J. (1998). An evaluation of the mound kiln carbonization technique. *Biomass and Bioenergy*, *14*(5-6), 505-516.

Silva, M. G. D., Numazawa, S., Araujo, M. M., Nagaishi, T. Y. R., & Galvão, G. R. (2007). Charcoal from timber industry residues of three tree species logged in the municipality of Paragominas, PA. *Acta Amazonica*, *37*(1), 61-70.

Sitoe, A., Salomão, A., & Wertz-Kanounnikoff, S. (2017). The context of REDD+ in Mozambique: Drivers, agents and institutions. In: Occasional Paper 79. CIFOR, Bogor, Indonesia. http://www.cifor.org/publications/pdf_files/OccPapers/OP-79.pdf.

Syampungani, S., & Chisanga, E. (2011). The influence of stump diameter and height on coppicing ability of selected key Miombo woodland tree species of Zambia: A guide for harvesting for charcoal production. *Journal of Ecology and the Natural Environment*, *3*(14), 461-468.

Syampungani, S., & Chisanga, E. (2011). The influence of stump diameter and height on coppicing ability of selected key Miombo woodland tree species of Zambia: A guide for harvesting for charcoal production. *Journal of Ecology and the Natural Environment*, *3*(14), 461-468.

Wang, S., Wang, K., Liu, Q., Gu, Y., Luo, Z., Cen, K., & Fransson, T. (2009). Comparison of the pyrolysis behavior of lignins from different tree species. *Biotechnology Advances*, *27*(5), 562-567.

Zulu, L.C., & Richardson, R.B., (2017). Charcoal, livelihoods, and poverty reduction: evidence from sub-Saharan Africa. *Energy Sustain. Dev. 17* (2), 127–137.

APPENDICES

Appendix A: Charcoal Producer Questionnaire

Producers: People who produce charcoal (or timber) from standing trees; [*Note. These are the laborers who do the physical work of cutting the tree, preparing and burning the stack of wood. If the business is owned – or the operation is funded – by someone else, that person is the trader, see below*];

As the Enumerator, you shall abide by these guidelines; Guarantee the respondent's anonymity and volunteerism, i.e., the respondent should not answer any question he/she doesn't wish to answer and can exit from the interview at any point he /she wishes.

Date:

Name of Enumerator:

County:

Subcounty:

Ward:

Location:

Sublocation:

Village:

Education level of respondent:

Age:

Ethnicity:

Gender of Respondent:

1. **Wood Harvesting/ Tree species preference**
   a. Which type of trees do you prefer? [local name is acceptable]
      i. Exotic species (*specify*)[In order of preference]
         Type 1
         Type 2
         Type 3
      ii. Indigenous species (*specify*)[In order of preference]
         Type 1
         Type 2
         Type 3

b. What is your experience in finding these preferred species? *(probe for whether the difficulties are increasing or decreasing relative to previous years. (What drives the difficulty or ease*)

c. How do you source for the wood? (*Tick where appropriate*)
   i. Cut trees [ ]
   ii. Wood residues from logging [ ]
   iii. Clearing forest for agriculture[ ]

d. At what diameter/girth do you cut the trees?

   i. Why that girth?
   ii. How many logs do you get from that girth of tree?

e. What do you do with the waste where you cut the trees?

f. Where do you mainly source your wood from? (*0-100%, Tick where appropriate, total must be 100%*)
   i. Government forest [ ]
   ii. Private forest [ ]
   iii. From own land [ ]
   iv. Others (specify) [ ]

2. Charcoal Production Process

a. What type of kiln do you use to produce charcoal?

b. How many bags of charcoal per kiln do you produce?

c. How many days on average does it take to carbonize the charcoal?

d. At what distance is the kiln from other trees in the forest on the production site? [*Ask for those who source in gazette forests*]

e. Do you let the wood dry before starting the carbonization process? [Y/N]

   i. [If Y] for how long?
   ii. [If Y] Why?

f. How long do you take to drive off the moisture in the wood before carbonization can take place?

g. Which parts of the trees do you use to make charcoal? (*Probe for the use of deadwood or live trees, and whether branches are left rotting in the forest or used)*

h. What measure do you take to prevent forest fires?

i. Has the way you conduct this activity changed over time? [Y/N]

    i. [If Y] How?

j. Do you plant trees after you are done with the production site? [*Probe what he/she does or can do, also probe for support of regeneration*]

k. Do you see yourself sourcing charcoal from the same portion of forest in the next 10 years? If not, why not? [*for producers who source trees from government forest*]

l. What do you consider as your key constraints in charcoal production?

m. Have you ever been apprehended at any point and time?

    i. What happens when apprehended? [*probe for whether they pay fines or they are just thrown in jail*]

    ii. How has it affected your operations?

n. How do you spend your time while producing charcoal? [*Probe for whether the producer does other activities in the forest while producing charcoal, e.g. bring cattle to graze, collect NTFPs, etc.)*

o. Do you produce alone or with the support of a team?

(*If team, probe for distinction of roles within the team, who cuts, who burn, who dig, who packs, etc., and how much they are paid per unit, and which unit, e.g. per month, per operation, per number of bags, etc.*) (Please also probe for youth or women in these roles)

Role	Amount	Unit	M/W/Y
E.g. burner	*KES1,000*	*1 bag*	*Mostly men*

p. What kind of tools do you use? (*Name the tool and put* O *for ownership and* H *for hired, also check for lifespan, e.g. if tool is owned, how much it cost and for how long it will last // if tool is hired, how much and for what period*)

Tool	O/H	Cost

q. How do you package the charcoal? (*Probe for use of recycled material*)

r. How much does the packaging cost? (*Please make sure the cost is per unit, e.g. per sack or bundle of 10, 20 etc. sacks)*

s. Is there any other cost incurred in the production process? (*Probe for any other costs the producer may have incurred*)

t. Once charcoal is ready and packed, do you sell it on the spot?

   i. If YES, how much are you selling 1 bag of charcoal for?
   ii. If YES, to whom do you sell it? (*Probe for traders, brokers, final consumers, etc.*)

[THIS SECTION from k-iii to l-v ONLY IF PRODUCER IS ALSO TRANSPORTING FROM THE PRODUCTION SITE]

iii. If NO, how do you transport it away from the forest? (T*ick:*

- Motor vehicle (specify type) [ ]
- Motorcycle [ ]
- Cart [ ]
- Walking [ ]
- Donkey [ ]

u. Where do you normally transport the charcoal? (*Probe if to loading point or a market etc. and the distance, in km)*

i. How many bags per trip do you transport?

ii. How much does 1 trip cost? (*Probe for total cost, including fuel, oil, driver if any, etc.)*

iii. How much are you selling 1 bag of charcoal for?[Probe for the different sizes they have to sell]

iv. During transportation to the client, do you normally incur costs along the route? (*Please probe for extra-legal payments, e.g. bribes, total amount and distance*)

v. Is a transport permit needed for transporting your charcoal to the client? (*Probe for cost and duration*)

[END OF SECTION]

v. Do you store charcoal when you remove it from the forest? [Y/N]

i. [If Y] Where do you store it?

ii. How long do you store it?

w. What are the points of loading charcoal? (*Probe for name of location and distance in km from the production site*)

i. Do they change periodically or it's always the same? Why?

(*Questions n-q below are to try and get an understanding of total production over the long term*)

x. How many bags do you produce in wet season? Dry season?

y. How many "bags" of charcoal do you produce in your best month? Worst month?

z. How many bags did you produce last month?

aa. How many good months are there in one year? How many bad months? [*If the total is not 12, ask how they rate the remaining months*]

   i. How long does one operation (i.e. the actions needed to produce those charcoal bags) last for? (*Get number of days and people employed)*

bb. Where and to who do you sell the charcoal? (*ask who are their main customers*)

   i. How often do you get orders for charcoal? (week? /month?)

   ii. Is there pre-ordering of charcoal?

   iii. Do the orders vary with seasons or are they constant?

Appendix B: Charcoal Transporter Questionnaire

Transporters: People who transport charcoal from one location to another (*may not necessarily be the final market. These people may be owners of the charcoal as well as owners of the means of conveyance, or even simply the drivers. It's an important node and we need to understand the costs/benefits for these people*);

As the Enumerator, you shall abide by these guidelines; Guarantee the respondent's anonymity and volunteerism, i.e., the respondent should not answer any question he/she doesn't wish to answer and can exit from the interview at any point he /she wishes.

1. Value chain activities of transporter

a. Is charcoal your main product transported? [Y/ N]
   i. [If Y] What other product(s) do you transport?
      1.
      2.

b. How frequent do you transport charcoal? [Tick where appropriate]

Duration	Number of trips
i. On a daily basis	
ii. Weekly basis	

   i. How many bags do you transport per trip? [indicate which site, e.g. production site or loading site]

   ii. Do you purchase the charcoal? [Y/N]

   iii. [If Y], how much do you buy the charcoal per bag?

   iv. What quantities of charcoal do you purchase?

c. Which destinations do you transport charcoal to? [*Try get Km radius from the loading site (include name of loading site)*]

d. Who are your clients? [*Probe which categories they fall under, e.g. private citizens, restaurants, church, schools, etc*.]
   i. At what measure of quantities do they buy the charcoal? [probe for the units of measurements e.g. 1 bag]
   ii. At what price do you sell the charcoal? [indicate price of the measured units of sale by the transporter]

e. Which means of transport do you use to transport charcoal? (*Name the mode of transportation and put O for ownership and H for hired*)

Mode of transportation	O/H	cost	Duration (If H)

i. Who owns the hired transport?
f. Why do you prefer this mode of transport?
g. Do you share the transport with other transporters?
h. [if Yes] How do you share transportation costs?
i. What do you consider as your key constraints in charcoal transportation?
j. Which times do you transport charcoal?

Appendix C: Charcoal Trader Questionnaire

Traders: People who both buy and sell charcoal, but don't sell directly to final consumers [*Note. These can be the owners of the business or funders of the operations in the forest, but do not conduct the operations in the forest themselves*];

As the Enumerator, you shall abide by these guidelines; Guarantee the respondent's anonymity and volunteerism, i.e., the respondent should not answer any question he/she doesn't wish to answer and can exit from the interview at any point he /she wishes.

Date: **Age:**
Name of Enumerator: **Ethnicity:**
County: **Gender of Respondent:**
Subcounty:
Ward:
Location:
Sublocation:
Village:
Education level of respondent:

2. **Value chain activities of charcoal trader**
   a. Do you prefer charcoal from any species [mention the local name if the scientific name is unknown]? If so which species and why?
      i.
      ii.
      iii.
      i. What has your experience been in sourcing for charcoal made of these species over the years? (probe for changes seen)

   b. Where do you mostly source your charcoal from? (probe for location e.g. roadside, market etc.)
   c. Whom do you purchase it from? (*probe for the costings of the purchased charcoal and from whom in the value chain they purchase it from*)

Purchase (from whom)	Restock duration	Bags purchased	Cost per bag	Total

d. Where do you sell your charcoal? (*probe for location of the trader's business premises e.g. stall in the market etc., how much they pay for the premises. Put O for ownership and H for hired*)

Premises	O/H	Cost/Rent/Duration

i. Who are your clients mostly?

e. How much do you sell your charcoal for per bag?
f. Do you have a minimum number of bags you sell at a go?
g. Do you handle logistics [travel arrangements] for your customers? [Y/N]

i. [If Y] Which means of transport do you use to transport charcoal? (*Name the mode of transportation and put O for ownership and H for hired*)

Mode of transportation	O/H	Cost/Duration

h. Which destinations do you mostly operate to? (*Probe for geographical scope of operation*)

i. What challenges do you face as a charcoal trader?

Appendix D: Charcoal Broker/Agent/Middlemen Questionnaire

Intermediaries / Agents / Brokers / Middlemen: [These people search out and/or organize charcoal supply for other people in the value chain *(i.e. do not buy and sell, but work on commission or contract for a trader or other actor in the marketing chain, or help producers secure access rights in production areas)*]

As the Enumerator, you shall abide by these guidelines; Guarantee the respondent's anonymity and volunteerism, i.e., the respondent should not answer any question he/she doesn't wish to answer and can exit from the interview at any point he /she wishes.

Date: **Age:**
Name of Enumerator: **Ethnicity:**
County: **Gender of Respondent:**
Subcounty:
Ward:
Location:
Sublocation:
Village:
Education level of respondent:

2. **Value chain activities of Middlemen**

a. Which categories of customers do you mostly deal with? [tick where appropriate]
   i. Producers [ ]
   ii. Retailers [ ]
   iii. Transporters [ ]
   iv. Traders [ ]

b. How often are your orders? [*probe for duration, e.g. weekly basis*]

c. Do you get commission per bag? [e.g. per bag of charcoal or per a certain number like every 10 bags of charcoal]

d. Do you handle logistics [*transportation arrangements*] for your customers? [Y/N]
   i. [If Y] Which means of transport do you use to transport charcoal? (*Name the mode of transportation and put O for ownership and H for hired*)

Mode of transportation	O/H	cost

ii. Is the transportation cost covered by the client?

e. Do you share transport with other brokers/agents? [Y/N]
   i. How do you share the costs?
f. Which challenges do you face in your line of work?

3. Source and Scale of charcoal brokered by Middlemen

a. Where do you mostly source your charcoal from? (probe for location e.g. roadside, market etc.)
b. Do you prefer charcoal from any species? if so which species and why?
   i.
   ii.
c. What has your experience been in sourcing for charcoal made of these species over the years? (probe for changes seen)

d. Which destinations do you mostly operate in? (probe for geographical scope of operation)
e. How many years have you been working as a charcoal broker/agent?

Appendix E: Charcoal Seller/Retailer Questionnaire

Wholesalers/Retailers: People who sell charcoal/timber directly to consumers

As the Enumerator, you shall abide by these guidelines; Guarantee the respondent's anonymity and volunteerism, i.e., the respondent should not answer any question he/she doesn't wish to answer and can exit from the interview at any point he /she wishes.

Date:
Name of Enumerator:
County:
Subcounty:
Ward:
Location:
Sublocation:
Village:
Education level of respondent:

Age:
Ethnicity:
Gender of Respondent:

1. **Value chain activities of charcoal sellers (source, quantity, costs and clientele)**
   a. Who are your clients? [*please probe which categories they fall under, e.g. private citizens, restaurants, church, schools, etc*.]

   b. Do you purchase the charcoal yourself? [Y/N]
      i. [If Y] How do you transport the charcoal you bought? (*Name the mode of transportation and put O for ownership and H for hired*)

Mode of transportation	O/H	cost

      ii. [If N] Who do you get your charcoal from? (probe for source e.g. producer, trader, broker etc.)

      iii. How much do you pay them per bag?

      iv. How often do you outsource your charcoal? [*probe for frequency and duration e.g. weekly basis, daily basis, monthly*]

c. Where do you buy your charcoal? [*probe for location and how long they have been getting charcoal from that location*]

d. Where do you sell your charcoal? [probe for location e.g. stall, roadside]
   i. Do you own it [*i.e. location of the space they sell charcoal*]?

   ii. [if N] How much does rent cost? [*Also probe for the duration the rent is usually due e.g. daily, weekly, monthly etc*.]

   iii. To whom do you pay rent to?

e. What is the distance between where you source for charcoal and where you sell it? [*Probe for name of location and distance in km*]

f. When purchasing charcoal, do you ask for particular tree species? [Y/N]

   i. [If Y] Which species?
      1.
      2.

g. What quantities of charcoal do you purchase? [*Probe for the no. of bags and its measurements in weight*]
   i. After what duration do you restock your charcoal?

h. What quantities do you sell your charcoal? [*probe for measurements that's they use to sell their charcoal and the price unit*]

Quantities/ measurements	Cost per unit

i. Did you get discounted prices if you buy a lot of bags of charcoal? [Y/N]
   i. [If Y] What amount of discount was offered?

j. Do you keep records of sales? Why?

k. Which challenges do you face as a charcoal seller?

Appendix F: Key Charcoal Stakeholders along the value chain

Table 1. 1: Key Charcoal Stakeholders along the Value Chain

Section	**Stakeholders**	**Roles**
Wood production	Tree owners	May manage his or her own trees
	Production	Sources for wood either legally or illegally
	Government institutions e.g. Forest and local authorities	Policy formulation Provision of technical support Licensing (tree cutting permit)
Carbonization	Charcoal owners	Provides the capital for the process
	Employees	Provides labor for charcoal preparation at site
Transportation	Transporters	Transports charcoal from production site to urban area
	Middlemen/Wholesalers	Buys charcoal from transporter to sell to retailers
	Government institutions e.g. police, forest and local authorities	Policy formulation Provision of technical support Licensing (movement permit, illegal taxes)
Vending (Wholesaling and Retailing)	Retailers	Purchases and sells charcoal at market or small shops
	Government institutions e.g. local authorities	Policy formulation Provision of technical support Licensing (Premise permit, illegal taxes)
Consumption	Households and institutions	Purchases and uses the charcoal for cooking, heating, water boiling etc.

Appendix G: Flat Jacket Calorimeter 1341 (Parr USA)

Appendix H: Data Collection Sheet

Data collection sheet

Date ……………………………..

Serial Number……………………

Tree species	**Moisture content**	**volatile content**	**Ash content**	**Fixed Carbon**

Type of Kiln	**Moisture content**	**volatile content**	**Ash content**	**Fixed Carbon**

Appendix I: Field Photos

Cleared big portions of land on either side of the road in Northern approach. The trees have been used for charcoal burning.

The remaining vegetation typology in Ainamoi and Kaorora.

Housing units belonging to Families seen in the foreground in Murichu squater village, neighbouring Mau West Forest (a prominent charcoal burning area). There are six other similar villages in the same neighbourhood.

Poverty has stalked the various land-squatters in Mau West Forest. This man has no other land to win for his family a good living. Mau West Forest is his only savior

Appendix J: NACOSTI Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **354537**

Date of Issue: **23/March/2020**

RESEARCH LICENSE

This is to Certify that Ms.. Ivy Maledi Amugune of Africa Nazarene University, has been licensed to conduct research in Kericho on the topic: ASSESSMENT OF VALUE CHAIN ACTIVITIES AFFECTING CHARCOAL PRODUCTION IN MAU WEST FOREST, KERICHO COUNTY for the period ending : 23/March/2021.

License No: **NACOSTI/P/20/4131**

354537

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY &
INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document,
Scan the QR Code using QR scanner application.

Appendix K: letter of Approval from Nazarene

AFRICA NAZARENE
UNIVERSITY

12th June, 2018

RE: TO WHOM IT MAY CONCERN

Ivy Amugune 17J03EMIT004 is a bonafide student at Africa Nazarene University. He/She has finished his/her course work and has defended his/her thesis proposal ***entitled "Assessment of value chain activities affecting charcoal production in Mau west forest, Kericho county, Kenya.***

Any assistance accorded to him/her to facilitate data collection and finish his/her thesis is highly welcomed.

Prof. Rodney Reed
Deputy Vice Chancellor, Academic Affairs