EFFICIENCY OF SAWMILLING TECHNOLOGY AND LUMBER RECOVERY IN KERICHO COUNTY, KENYA

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DECLARATION AND APPROVAL

Declaration

This thesis is my original work and has not been presented for the conferment of a degree or for the award of a diploma in this or any other University:

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DEDICATION

This thesis is dedicated to my wife Georginah Mueke, who taught me that the best kind of knowledge to have is that which is learned for its own sake; my son Leon Mueke and my daughter Ella Mueke. It is also dedicated to my parents Mulwa Nzinga and Keziah Mulwa, who taught me that there is no limit to how good you can get in pursuit of perfection.

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ABSTRACT

Conservation of forests is slowly shifting into a more proactive approach such as efficient lumber conversion in Sawmills. Traditional lumber conversion of Kenyan wood species has heavily relied on chainsaws that have low lumber recovery. There's need therefore to explore the use of modern Sawmilling machinery in lumber conversion that produces low residues and wastage and hence high recovery. The turnover of log supply in saw mills increases with poor conversion techniques due to high wastages resulting to harvesting trees above the specific annual allowable cuts. Utility efficiency can lead to relative conservation. It is against this background that this study looked into the production capacity, efficiency and recovery rates of *Cupressus lusitanica* and *Pinus patula* lumber from selected Wood-mizer (LT15, 20 and 40) Sawmilling machinery in Kericho County, Kenya. Logs delivered to each respective Sawmill yard were categorized into ten diameter classes from 10 to 59cm for both species. Volume of four logs from each class and species was evaluated using Huber's formula and converted using through and through sawing technique into lumber. Volume of the lumber pieces and residues obtained were measured. The time taken during the conversion process was also recorded in order to determine the efficiency and lumber production capacity of each Sawmill machines. Data were systematically analyzed for relations using descriptive statistics and means through paired sample t-test in SPSS. The study identified a total of 54 registered and prequalified Sawmills (four large scale, 12 medium scale and 38 small scale) located within Kericho County. 30% of these Sawmills are located around Kericho town and 22% in Londiani, with 89.4% having been in operation for more than 10 years. 74.4% of the Sawmills had only one primary conversion machine in comparison with 25.6% who had 2-4 machines and on average five (5) employees. 42.6% of the Sawmills operate up to 8 hours daily while 6.4% operate between 5 and 12 hours daily. Sixty percent (60%) of the Sawmills are LT15, 26.7% (LT20) and 13.3% (LT40). Conversion efficiency of Wood-mizer LT15 was classified as low (48.3%), in comparison with LT20 which was classified as moderate (41.9%) and LT40 as high (60%). Recovery of *C. lusitanica* gave average empirical values of 43% for Wood-mizer LT15, 49% for Wood-mizer LT20 and 53% for Wood-mizer LT40. Recovery of *P. patula* gave average empirical values of 39% for Wood-mizer LT15, 34% for Wood-mizer LT20 and 60% for Wood-mizer LT40. LT40 gave the highest recovery rates (74% and 87%) for different top diameter classes of *C. lusitanica* and *P. patula* respectively. *P. patula* produced the most residues at 61% and 66% compared to *C. lusitanica* at 57% and 51% per log volume for LT15 and LT20 respectively but less from LT40 (47% for *C. lusitanica* and 40% for *P. patula* logs. Wood-mizer LT40 recorded the highest daily (8 hours) production capacity for both *C. lusitanica* and *P. patula* (15.9 m^3/day and 16.2 m^3/day) respectively. This was followed by Wood-mizer LT20 at 11.2 m^3/ day and 9.6 m^3/day for *C. lusitanica* and *P. patula* respectively. Wood-mizer LT15 had the least production capacities of 8.8 m^3/ day and 9.9 m^3/ day for *C. lusitanica* and *P. patula* respectively. These results suggest adoption of the selected Wood-mizer Sawmill machinery in Kenya for sustainable forest resource management.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAC	Annual Allowable Cut
ANOVA	Analysis of Variance
CBD	Convention on Biological Diversity
CCD	Convention to Combat Desertification
CIFOR	Centre for International Forestry Research
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DBH	Diameter at Breast Height
EIA	Environmental Impact Assessment
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
JFM	Joint Forest Management
JICA	Japanese International Cooperation Agency
KFS	Kenya Forest Service
Km^2	Square kilometer
KNBS	Kenya National Bureau of Statistics
LRF	Lumber Recovery Factor
MFC	Mau Forest Complex
NACOSTI	National Commission for Science, Technology & Innovation
NGO	Non-governmental Organization
NWFP	Non-wood Forest Products
SDGs	Sustainable Development Goals
SRSWOR	Simple Random Sampling without Replacement
UN	United Nations

UNDP United Nations Development Programme

UNEP United Nations Environment Programme

DEFINITION OF TERMS

Annual allowable cut is the maximum volume of timber that may be harvested on an annual basis from a forest management unit.

Back pulling is a technique of felling a tree whereby it is fell against its natural lean.

Baulking sawing method is whereby during sawing, the saw lines meet the growth rings at more than 45^0

Bucking is the process of converting or cutting felled and limbed trees into sizeable logs for lumber production.

Cant is an edged log or a log with at least three of its sides cut into a right angle forming either a cross-sectional triangle or square shape. It is from this that sized planks are cut.

Delimbing is the removal of side branches from a felled tree during the process of logs making.

Dimensional lumber is timber cut according to specific standard market measurements of width and depth. The measurements are most of the times in inches.

Felling is the cutting down of trees during the process of logging.

Forest cover is the amount of land area covered by a forest.

Forest refers to a land area of more than 0.5ha with a canopy cover of at least 15% and trees of minimum height of 2m *in-situ*.

Green allowance is the extra lumber thickness on top of market specifications included during sawing to cater for shrinkage due to potential moisture evaporation and planning.

Head saw is an instrument which usually makes the initial cut into a log. It can be used for debarking and conversion of the log into a cant or planks.

Kerf is the channel left behind by a saw cutting through lumber and a relative measure of this channel's width. This width is affected by factors like blade width, blade wobble, the sawdust amount, and the teeth set.

Log debarking is the removal of the bark of a tree. This usually leads to the formation of cants in Sawmilling.

Log decking is the sorting of logs according to tree species, sizes, market requirement and other characteristics of interest. It is done most of the times before debarking and the process of lumber conversion.

Log scaling is measuring a cut tree to determine the size, density, volume, grade and other qualities of interest as dictated by market specifications or the intended use.

Log skidding is the removal of logs manually or using special machines or equipment called skidders from the point of tree felling to the point of lumber conversion.

Log taper is the degree to which a log decreases in diameter as a function of length.

Logging is the felling, delimbing, bucking, skidding and on-site processing of trees into logs.

Lumber conversion efficiency is the ratio of the useful lumber output and the log input.

Lumber is wood processed into beams or planks in the process of Sawmilling.

Lumber production capacity is the maximum possible lumber output of a Sawmill per unit time.

Lumber recovery rate is the percentage of the volume of sawn wood output to that of the volume of log input processed in the Sawmill.

Milling rates refers to a measure of the quantity of lumber converted from logs per unit time.

Prequalified Sawmills are those qualified in advance to take part in official tree tendering with Kenya Forest Service.

Production capacity is the output a business process can produce in a given time with finite resources under expected and normal conditions.

Recovery rate is the percentage of output to that of the input.

Registered Sawmills are those entered or recorded on an official list by Kenya Forest Service

Resaw is a type of band used for sawing lumber along the grains that usually minimizes losses because of the small kerf.

Sawing variation is a change or slight difference in in the movement of saw blades through wood during Sawmilling. It is generally a measure of the functioning of the set works of a sawing machine.

Sawmill is a facility or a place where logs from trees are converted into cants and eventually lumbers.

Through and through sawing method is a type of lumber conversion whereby saw lines are placed with respect to the sawn lumber thickness.

Top diameter is the diameter of a log at its distal (thinner) end.

Tree driving is a technique of felling a tree whereby one tree is fell into another to help bring them both down.

Tree Cover is area covered by tree patches of size less than 0.5 hectares

Utility efficiency is usage of a resource with little to no waste, effort, or energy.

Wood-mizer is a company that makes portable saws which are small and easy to move around. This name also refer to the machines made by the company. These machines usually have serial names like LT15, LT20 and LT40.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This chapter presents the background of the study, problem statement, objectives and research questions. It also covers justification, significance, scope and assumptions of the study.

1.2 Background of the Study

Wastages during lumber conversion increase due to the type, condition and maintenance of mill equipment and decision making by sawmilling crew. Sawmills normally acquire logs from both public and private forests, transport them to Sawmills and convert them into lumber according to market requirements (Ekhuemelo, 2015). In the process, wood residues are generated (Elijah, 2011). Most of Sawmills in Kenya are characterized by small scale operators who mostly process lumber with chainsaw machines. Lumber recovery, which is defined as the percentage of the volume of sawn wood output to that of the volume of log input processed in the Sawmill, regardless of the type and kind of processing equipment adopted and the species of wood involved is low, (Ekhuemelo, 2015).

Utility efficiency can lead to relative conservation (FAO, 2010). This is because by ensuring all stages that raw materials undergo are extensively sustainable will reduce the turnover with which the same raw materials are processed. Trees are a renewable resource, however if this endowment is misused and misinterpreted, the process of their replenishment can be long, expensive and painful. This is especially true and applicable in the field of forestry where the key agenda of operation is usually conservation and sustainable utility. Trees unlike most other plants have a long rotation age. Trees, especially some indigenous ones may even take half a century to mature (Matiru, 1999). The practicality of sustainable utility in this regard becomes theoretical. To make a continuous harvest of such species, a model that puts into consideration both the rotation period and efficiency in utilization must be given priority over all other models.

Whereas most emphasis has conventionally been placed on the impact of conservation of forest resources in Kenya, further efforts can be trickled down to the utilizers of the forest products to ensure that their processes are extensively sustainable. It is therefore not sufficient to only focus on the forest conservation and disregard the forest utilization. Poor utilization processes lead to frequent harvesting which lead to low regeneration periods that consequently leads to forest destruction, (Muisyo, 2018).

Failure to implement the prescribed tree harvesting plans in this sense, as a result of poor intermediate conversion techniques, among other factors, can only jeopardize the needs of the future generations (Wilson, 1994). Some Sawmills convert logs into lumber using the rule of thumb. This is through the use of the traditional Chainsaws that leave a wider kerf resulting into huge losses on volume (Marfo, 2009). In addition, such saws are poorly adapted to dealing with logs affected by defects and log taper. A sustained flow of lumber is the key management objective for forest resources. This is achieved by cutting equal amounts of tree resources over regular intervals. If this is to be achieved, then the idea of a 'normal forest' must be employed. Age structure of all plantations must conform to this. The turnover of log supply to Sawmills increases with poor conversion techniques, due to high wastages and increasing demand, resulting to harvesting trees above the specific annual allowable cuts (Josip, 2009). This has necessitated a close examination of Kericho County sawmilling activities.

Even tree species like Eucalypts which take relatively shorter period of time to be market ready experience over-demand (Langat, Cheboiwo, & Muchiri, 2015), which consequently impact negatively on their sustainability as efficient sources of lumber for the current and future generations. Usually, trees, both on private farms and government gazetted forests are harvested at rotation age. This explains why it is rare to find over-mature trees with large Diameters at Breast Height (DBH) growing on privately owned farms (Langat et al., 2015).

The current global economy is capitalistic (Frieden, 2011) where everything has a price and everything can be sold if one is willing to pay. Even though such an economy is ideally effective for the theme of global urbanization, its main side effect in forestry is the fast depletion of resources. This depletion becomes a major challenge when the resources take a long period of time to be re-established as is the case for trees. The challenge in the case of trees in Kenya is more severe because of high population and the changing lifestyle from the predominantly rural livelihood to urban settlement (Ministry of Forestry and Wildlife, 2013). There has been rampant excision of natural forests in Kenya for crop farming and settlement. A review of the Kenya Gazette notices reveals that between 1994 and 1999, a total of 701.52 hectares were proposed for de-gazettement while6, 442.5899 hectares were officially de-gazetted (Matiru, 1999). Apart from reducing the total forest cover in the country also increases the shortage of wood and non-wood forest products (NWFPs). This increased shortage interplays with commercial demand and supply factors and leads to increased product prices due to increased products demand. The increased prices and demand motivates Sawmillers to vigorously look for the saw logs leading to the destruction of forests through either illegal harvesting or overharvesting of the products from natural and protected forests (FAO, 2008), among others.

Whereas, a complete ban on the utilization of forest products is neither practically nor theoretically attainable, the emphasis on the sustainability and conservation of the forests and their products is still a global concern, especially for organizations like the Food and Agriculture Organization of the United Nations (FAO, 2010). Priority therefore has shifted to the sustainable use of the available forest resources. Sustainability includes efficient utilization of available resources to avoid wastage, maximize value and promote longevity.

It is with this background of improving the utilization of forest products that this study embarked on the determination of the conversion efficiency, production capacity and recovery rates of logs during Sawmilling. Sawmills are the primary utilizers of wood from forests and privately owned farmlands in Kenya. It is because of this that Sawmills and other companies that primarily consume wood as a raw material are located near forest reserves.

As noted by Wade, Bullard, Steele and Araman (1992), “The efficiency with which hardwood Sawmills convert logs to lumber has become increasingly important”. They attribute this newfound importance to the need to realize high business profits and the need to ensure that resources last much longer. There are however many factors that affect the Sawmilling efficiency and lumber recovery, (Steele, 1984). These factors include sawmilling technologies. For instance, the lumber production rate for the Wood-mizer machines is estimated to vary from 0.75 m^3/hour for Wood-mizer LT15, 0.95 m^3/hour for Wood-mizer LT20 to 1.3 m^3/hour for Wood-mizer LT40, (Wood-mizer, 2018).

1.3 Statement of the Problem

As noted by Albert Einstein, "It doesn't matter how many resources you have, if you don't know how to effectively use them, they will never be enough." The conservation of our natural resources and their proper use constitute the fundamental problem which underlies almost every other problem of our life. On February 24th, 2018, the Kenyan government issued a moratorium on logging in the country and directed the Ministry of Environment and Forestry to form a Task Force to undertake an audit of the forest cover in the country. This intervention was as a result of an outcry from the members of the public on unsustainable utilization of forest resources whereby tree harvesting limits in the country were exceeding the prescribed annual allowable cuts, affecting water levels.

According to the Kenyan Ministry of Environment and Forestry, in 2016 Kenya had a wood supply potential of 31.4 million m^3 /year against a national demand of 41.7 million m^3/year hence a current deficit of 10.3 million m^3/year. Therefore, the demand for wood overwhelms the supply, a factor that leads to the encroachment of both public and privately-owned forests. This can be partly offset by ensuring that the harvested trees are used optimally. This optimal utilization on the other hand is a function of the production process which in turn is affected by the machines used and the time taken on the production chain. Thus, exploitation of forest resources for industrial purposes if not well planned may be deleterious to the environment. Improving on lumber recovery will lead to the strategic savings on the same resources.

The lumber recovery and sawmilling efficiency of Wood-mizer machines used in Kericho County is little known. Sawmills in Kericho convert logs into lumber mostly using chain saws and Wood-mizer machines. Converting lumber using traditional Chainsaws leave a wider kerf that result to huge losses on volume which in turn leads to increased log turnover in Sawmills. The unsustainable loss of trees and other vegetation can cause climate change, loss of biodiversity, damage to natural habitats, disturbances in the water cycle, desertification, soil erosion, increased greenhouse gases in the atmosphere among other factors. Using the right machines in sawmilling will not only give advantage to the lumber output, ease of operation, but also ensure savings on trees as a raw material.

In addition, the Lumber Production Capacity of Wood-mizer machines in Kericho County is little known. Lumber Production Capacity is very important while designing a Sawmill business process. If a Sawmill invests too much into production capacity and the demand in the market is less, then a lot of produced lumber can go waste. If the Sawmill doesn't use the planned capacity, then the business is losing the money it invested in building the capacity. Not Knowing your Sawmill production capacity and having the knowledge you need to be able to improve it denies a Sawmill the chance to plan better, schedule more efficiently, and give customers more accurate lead times and forecasts. Applying the knowledge of a Sawmill's production capacity ensures buying raw materials, equipment and other inputs so that the production capacity only meets the demand. This will go a long way in saving the two commonly grown plantation species in Kenya- *C. lusitanica* and *P.patula* trees. This study therefore contributed to the wider goal of optimal utilization of saw logs.

1.4 General Objective

The general objective of this study is to evaluate the efficiency of Sawmilling technology and lumber recovery in Kericho County.

1.5 Specific Objectives

The following were the specific objectives;

a) To document the status of Sawmills in Kericho County.
b) To determine conversion efficiency of *Cupressus lusitanica* and *Pinus patula* lumber using Wood-mizer LT15, LT20 and LT40 machines
c) To determine the milling recovery rates of Wood-mizer LT15, LT20 and LT40 machines
d) To determine production capacity of *Cupressus lusitanica* and *Pinus patula* lumber from Wood-mizer LT15, LT20 and LT40 Sawmill machines.

1.6 Research Questions

The study focused on finding the answers to the following questions.

a) What is the status of Sawmills in Kericho County?

b) What is the *Cupressus lusitanica* and *Pinus patula* lumber conversion efficiency using the LT15, LT20 and LT40 Wood-mizer machines?

b) What are the milling recovery rates of LT15, LT20 and LT40 Wood-mizer machines?

c) What is the *Cupressus lusitanica* and *Pinus patula* lumber production capacity from the Wood-mizer LT15, LT20 and LT40 machines?

1.7 Justification of the Study

Efficiency in utilization of forest resources helps to estimate the resource sustainability. Therefore, recovery rates records of selected Wood-mizer machines will inform Sawmills on best lumber conversion machines thus contributing to sustainable resource use by ensuring that the County's annual allowable cut is not exceeded. In addition, knowledge on lumber production capacities for different Wood-mizer machines will help Sawmillers better plan and schedule production, give more accurate lead times, and forecast their cash flow. Since the Kenya Forest Service allocates forest materials only to pre-qualified Sawmills and on the basis of their level of operation, there is need to have a well-informed categorization of Sawmills (GOK, 2009). In addition, there is need to have comparative information on sawmilling machines used for lumber conversion. Even though the study borrows the backgrounds and methodologies of other past studies, it is both new and unique in terms of the machines under study. The study targeted *Cupressus lusitanica* and *Pinus patula* tree species. This is because *Cupressus lusitanica* and *Pinus patula* are not only the two major plantation species grown in Kenya but also the most preferred lumber species. The study is also new in the geographical location of interest and the general purpose and need to undertake the study. Sawmills operating in Kericho County were chosen because apart from being the parent County for the University of Kabianga that promotes innovation and research, the County is also one of the greenest in Kenya with 23.23% tree cover, (Kenya Forest Service, 2021) that is attractive for Sawmilling. Apart from hosting part of the Mau Forest, Kericho County hosts quite a number of Sawmills and tea factories which utilize wood from trees as a raw material. This utilization not only places pressure on the available wood sources, but also creates an insatiable need for growing trees both on-farm and in forest reserves. There are also a number of registered Sawmills in the County which necessitates a need for researchers to investigate the sustainability of these Sawmills with respect to the available resources. The study focused on Wood-mizer machines in the County because they are the primary machines used by Sawmillers.

Minimization of loss and wastage will translate to sustainability, the prevailing paradigm that the globe is shifting towards through the Sustainable Development Goals (SDGs). The SDG number 15, that is, 'Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss' (UN, 2015), is an example of the intended shift to a sustainable environment through sustainable utilization of natural resources.

Extending the concept of sustainability to incorporate the utilization efficiency of the limited lumber resources is the key justification of this study. The study also expands its scope to look at the production capacity of the Wood-mizer machines in order to gauge whether they have underutilized potential and the effect the utilization of that full potential would have on the forest resources conservation in Kericho County and adjacent regions.

1.8 Significance of the Study

Efficiency in utility of forest resources is a pointer of their sustainable use which leads to ensuring forests produce goods and services for posterity. Understanding the current status of sawmilling in Kericho County is a key step in building a Sawmill's awareness of the need for change in lumber conversion technologies. By developing a baseline of current state of sawmilling, it allows one to visualize the bottlenecks and agree on the priorities. Understanding lumber recovery rates, production capacity and conversion efficiency provides data useful for planning and achieving sustainable use of forest resources in the County. The study also intended to collate meaningful data that can be used as primary reference for future studies that have interest in the Sawmilling activities and the applicable machineries. The guiding principle of this study of extending sustainability studies to include the resources utility efficiency is also quite significant when widely disseminated. Many resources usually go to waste during the extraction and processing and thus the concern on how these losses can be curbed or minimized. This is a key factor in the conservation of forestry resources world-over.

This study findings will also help Sawmills critically examine their processes and come up with the most effective machineries and technologies that can get the work done faster at a lower cost. Whereas it is evident that there must be losses during the lumber conversion process, this study emphasizes on the benefits of saving through loss minimization, a key factor in the profit margin improvement for Sawmills. Understanding a Sawmill's production capacity allows better planning and scheduling lumber production of *Cupressus lusitanica* and *Pinus patula* lumber.

The findings of the study will also give meaningful data to Kenya Forest Service for designing forest advisory services programs to tree growers. Programs that target waste minimization in tree utilization will ensure farmers get optimum value for their tree crops.

1.9 Scope of the Study

The geographical scope for this study was Kericho County. This thus translated statistically into the inference limits that would only best describe Kericho County and its immediate matching environment. However, it should be worth noting that because the study primarily focused on the machinery used by Sawmillers and the lumber conversion of *Cupressus lusitanica* and *Pinus patula* tree species, some of its findings might have a wider scope of application and replication. The findings might be applied in other tree species of the Cuppressus and Pinus genuses. Apart from log diameter, other factors like log length, taper, and quality affect wastages in wood processing with Wood-mizer machines. The Wood-mizer machines included as samples in the study were those commonly used by Sawmillers in the County, LT15, LT20 and LT40. The study was carried out in 2019, a period of nationwide logging ban in public forests. Saw logs were obtained from private forests. Three Sawmills were selected for a detailed data analysis; Dormer, Timsos and Lel timber Sawmill.

1.10 Limitations of the Study

The study did not look at the factors that impact on lumber recovery. Factors like log diameter, taper and quality, product mix, decision making by the sawing crew, condition and maintenance of mill equipment and sawing method might have impacted on the accuracy of the data that was derived by the study and the subsequent analysis. During log selection, logs were classified as either poor quality or high quality to address errors resulting from log taper.

Wood-mizer machines are powered by electricity. Data collection during power outages was to therefore be affected and hence compromise the accuracy of the knowledge generated. To address this, data was collected only when there was electricity.

Another limitation worth noting was the fact that the study took place during a period of nationwide ban on tree cutting and harvesting (Muisyo, 2018). Sawmills therefore reported lower activities than the norm. To address this, sawmills were considered based on their functionality.

1.11 Assumptions of the Study

This study assumes that lumber processed by Sawmills is mainly derived from Kericho County. Whereas this might not be true, it helped a great deal during the inferential phase after data analysis. The study also assumed homogeneity among the sampled Sawmills in terms of labour availability and expertise, capital allocation and raw materials availability. In addition, the study assumed homogeneity in log taper and quality and over-sizing for green allowance considering saw logs were sourced from private forests. The study also assumed homogeneity in sawing variation between different machines. In addition, the study assumed homogeneity in the condition and maintenance of mill equipment within various Sawmills. Whereas these assumptions might as well be erroneous, they helped standardize some of the factors that might affect the Sawmilling activities.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents the theoretical framework, discusses the related literature to the primary research objectives, evolution of sawmilling, the process of sawmilling, lumber conversion methods, state of sources of saw lumber in Kenya, equipment and machinery in sawmilling, lumber conversion efficiency measurement, lumber recovery rate measurement, lumber production capacity measurement, possible knowledge gap that the study intended to fill and a conceptual framework.

2.2 Theoretical Framework

A number of theories of environmental sustainability exist (Dragulanescu, 2013). The neoclassical theory is the extended version of the classical theory wherein the behavioral sciences gets included into the management. The neoclassical approach is based on the assumption that the capacity for self-regulation (Tietenberg, 2006) of free markets and technological advances are able to ensure capacity of substitutions endless between the various forms of capital, mitigating so, the constraints arising from the possible scarcity of resources that allow sustainable growth. Efficiency in sawmilling technology is critical in boosting recovery rates and increasing the lumber production capacity in Sawmills. Technology can play an important role in creating lean and efficient processes, help reduce or eliminate duplications and delays in the workflow, as well as help speed up by automating specific tasks.The rule provides that if royalty or user cost (Tietenberg, 2006) generated by the extraction, according to an efficient plan are fully saved and reinvested in renewable capital, the level of resulting investment would be sufficient to provide a value of the capital stock (economic) at least constant over time. Thus it is possible that consumption levels remain non-decreasing with exhaustible resources hence contributing towards sustainability of the forest resources (Muisu, 2003). According to this theory, the organization is the social system, and its performance does get affected by the human actions. Decision making by sawmilling crew will thus affect the lumber conversion efficiency, recovery rates and output levels.

Neo-Malthusianism theory is the advocacy of population control programs to ensure resources for current and future populations. Even though there are several debates and theories e.g. Ester Boserup's theory against the Malthusians theoretical framework, this study was based on the modification of the same. Whereas Malthusianism focuses on population control for sustainability, this study focused on the extracted resources utilization control for sustainability. Technological progress increases the productivity of resources and thus to ensure that available resources will last longer and longer. Therefore, it is believed that the economy will evolve in such a way that economic growth reduces more and more its environmental effects. Efficient sawmilling technology will optimize the value of forest resources and ensure wastages are minimal. The value of forest resources quality and the concept of waste assimilation capacity as a resource to be managed have been taken seriously since the mid-twentieth century. Forest resources and sustainable utilization remain a core component of a coherent sustainability agenda, with relevance at the macro level - how do the essential concepts of forest resources sustainability fit together and the micro level - where the details and particulars of sustainable utilization of forest resources are studied theoretically and empirically to ensure that the utilization is not only efficient, but also the lumber recovery rates are optimum at the best production capacities (Susanna *et al*, 2016).

2.3 Review of Related Literature

This section presents the related literature to the primary research objectives, historical and emerging issues that are related to sawmilling in the context of this study. The history, the process, the machinery, the various concepts and calculations involved in the tree conversion processes are described herein.

2.3.1 Evolution of sawmilling technology

Sawmilling is the process of operating a Sawmill through converting logs into lumbers. Although the general workflow of the modern Sawmills resembles the workflow of the ancient Sawmills where logs are converted to dimensional lumber, there has been tremendous improvement in the efficiency of work in terms of mechanization and efficiency indices (Callaway, 2010).

In the pre-industrial revolution eras, most of the Sawmilling processes were done using manual techniques and skills. Trees were cut down using axes and converted into logs using manual saws. They were then skidded by water to the Sawmilling points in order to be converted into lumber. There were several hand held saws operated by at least two people that were used for debarking, cants formation and final planks sawing. Pit sawing was one of the most popular techniques for sawing logs along the grain (Callaway, 2010).

Because log skidding was mainly done by water, the location of Sawmills was dictated by the availability of water bodies and the direction of water flow. This could have caused a challenge for trees harvested in places that were away from water bodies. The invention of Sawmills whose blades were powered by water improved the efficiency of Sawmilling but again meant that Sawmills more than ever depended on water availability for most of the activities (Moore, 2017).

Industrialization led to the improvement of the processes where hydraulics was introduced into the process and automation was incorporated. This among other things led to the development of portable Sawmills. Portable Sawmills meant that Sawmilling could be done *in situ* and only the finished products transported to the target areas of use and/or market. *In situ* processing meant that the skidding costs and inconveniences could be mitigated. Better fuel-propelled chainsaws were also developed to facilitate tree felling and some of the *in-situ* processing steps.

The emergence of the Chainsaws coincided with the logging ban in Kenya. Before 1999, chainsaw milling was insignificant, since sawmills were able to meet the demand for sawn timber. Consequently, the ban on wood harvesting from government plantations, however, resulted in an acute shortage of timber. This prompted increased imports from neighboring countries and cross-border timber trade, both legal and illegal Trees on farms became the principal alternative, and quickly made up a significant proportion of all traded timber. (Muthike, Shitanda, Kanali & Muisu, 2010).

The modern-day Sawmilling equipment keep reducing in sizes and improving in automation. They have improved in portability and power (Callaway, 2010). Some of these machines and equipment are discussed in the section on Equipment and Machinery in Sawmilling.

There are several types of Sawmills in the lumber industry as a result of different classification criteria that include the size, the wood converted or the end products. In terms of the wood converted by Sawmills, we can have softwood Sawmills and hardwood Sawmills. In terms of the products produced, we can have stud mills and pulp mills (GlobalSpec, 2018). Sawmills included in this study were classified in terms of size, that is small, medium and large, as classified by the Kenya Forest Service in 2012.

2.3.2 Process of sawmilling

The first step in Sawmilling is scouting for mature trees. These are trees that have reached rotation age and have diameters that are large and mature enough to produce quality dimensional lumbers. Felling of the identified trees is done using different felling techniques such as tree driving and back pulling. The fallen trees are then delimbed to remove the side branches and leaves from the trees. The branchless tree undergoes log bucking where the entire length of the tree is cut into manageable log lengths as per market specifications. The resultant logs are then skidded either physically or using machines called skidders to the transportation vehicles, lumberyard or Sawmill. The logs are scaled and decked to determine their appropriate utility and sawing techniques that will best convert the logs into lumber (FAO, 1990).

The bark on the logs is removed in a process called debarking. There are usually some lumber losses incurred during this process; especially when the log being debarked is not fairly straight. The logs are turned into cants that are eventually turned into planks of standard dimensions that match the market demand or the intended use. This can be done using different types of saws that include the head saws and resaws. The standardized planks are then edged, trimmed, dried and stored or transported to the target market or use (FAO, 1990).

Modernization and process mechanization has led to the development of machineries that make the process of Sawmilling simpler and more efficient right from the tree felling stage to the planks drying stage. There are machines that can handle and simplify these steps to make Sawmilling both easy and fast. The Sawmilling business has generated quite some interest to stakeholders. In terms of the practice, there exists various Sawmill processes, (FAO, 1990).

2.3.3 Lumber conversion methods

Not every saw log is straight and cylindrical in shape. Generally, logs are commonly out-of-round, tapered, or crooked, and often a combination of these shapes. Log buyers have scaling and grading rules in place to avoid paying for yield losses from out-of-shape logs. Also Sawmill operators employ every means to recover as much yield from each log as possible. Thus, more lumber output can be extracted if the sawyer develops a sawing plan for each log that minimizes the potential yield loss that frequently results when sawing out-of-shape logs. This extra board footage can be the difference between a profitable and a non-profitable log, (United States Department of Agriculture, 2014)

Lumber may generally be sawn in one of the following ways:

2.3.3.1 Through and through sawing

In this method, the log is moved backward and forward on the platform of a Sawmill. This method is also called tangential sawing. It is one of the preferred sawing methods in Kenya. It is an easy, fast and economical method which minimizes wastage of useful lumber. However, the planks obtained by this method are liable to warp and twist as a result of unequal shrinkage.

2.3.3.2 Radial sawing

The sawing is done parallel to the medullary rays and perpendicular to the annular rings. The cut section shrinks at a uniform rate and warping is therefore less. This method is generally used in the conversion of hardwood lumber for high-quality lumber works. The wastage of wood is more in this method than through and through method and it takes a longer time for conversion due to the keenness required to execute the method.

2.3.3.3 Quarter sawing

In this method, the sawing is done at right angles to the medullary rays and tangential to the annular rings. In addition, due to the cutting of the medullary rays, the sections cut become weaker. The log is first quartered lengthwise, resulting in wedges with a right angle ending at approximately the center of the original log. Each quarter is then cut separately by tipping it up on its point and sawing boards successively along the axis.

2.3.3.4 Baulking sawing

This is a method of lumber conversion whereby the log is first divided into quadrants. The saw cuts are then placed at right angles to each other. In this method, there is a tendency for the lumber to bend in a transverse direction. This method is also preferred by Kericho County Sawmills. Figure 2.1 illustrates various lumber conversion methods, (United States Department of Agriculture, 2014).

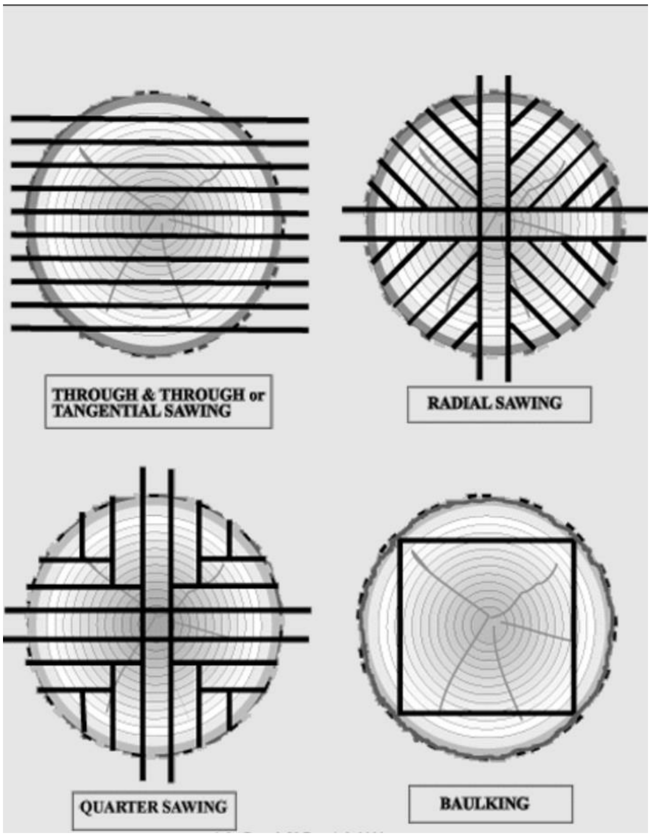

Figure 2.1: Lumber Conversion Methods

2.3.4 State of sources of saw lumber in Kenya

2.3.4.1 State of gazetted forests in Kenya

Kenya has a land mass of 59,196,877.24 hectares, of which 5,226,191.79 hectares is covered by forests equating to a forest cover of 8.83%, (Kenya Forest Service, 2021). Kenya also has 7,180,000.66 hectares of tree cover translating to 12.13% of the land mass. The National Forest Resources assessment conducted in 2021, also established that the distribution of forest types in the country is such that natural forests occupy 84%, plantations 11%, Bamboo 4% and mangroves 1%, (Kenya Forest Service, 2021). Gazzetted public forests managed by Kenya Forest Service on behalf of the National Government cover 2.6 million Ha.

Forests play a vital role in the provision of ecosystem goods and services. Forests support key ecological functions, are the main source of water, play a key role in the production of energy and act as carbon sinks in mitigating the impacts of climate change. For instance, the contribution of the forest sector to the Gross Domestic Product GDP is estimated at USD 365 million (3.6%) annually, (Kenya Forest Service, 2017). Table 2.1 illustrates the age class distribution of gazetted forest plantation area in Kenya totaling to 152,823.90 hectares. In this area, 129,665.3 hectares is stocked with exotic tree species, 12,084 hectares with indigenous tree species and 11,084 hectares being un-stocked, (Kenya Forest Service, 2021).

Table 2.1

Age Class Distribution of Gazetted Forest Plantations in Kenya

AGE	Age Class Distribution (Ha)
1-5 years	25,647.30
5-10 years	20,209.20
11-15 years	13,399.90
16-20 years	15,115.90
21-25 years	9,888.20
26-30 years	5,343.70
More than 30 years	40,051.10
Indigenous	12,084.6
Un-stocked	11,084.00
Total	152,823.90

Source: Source: Kenya Forest Service, 2019

2.3.4.2 State of gazetted forests in Kericho County

The total County tree cover stands at 23.23% while the forest cover stands at 20.61%, (Kenya Forest Service, 2021). County forests cover 63,179 ha. Out of this, 49,746.6ha comprises of indigenous forest while 13,432.4 ha falls under industrial plantations. The major tree species growing in the plantations are *Cupressus lusitanica* (60% of total plantation area), *Pinus patula* (30% of total plantation area), and *Eucalyptus saligna* (5% of total plantation area).

Table 2.2 shows the distribution of gazetted forest areas in the County. Kericho Forest Station has the largest forested area followed by Londiani Forest Station. Tendeno Forest Station has the smallest forested area of 2,341.65 hectares.

Table 2.2

Gazetted Forests in Kericho County

Forest Station	Plantation Area (Ha)	Indigenous Forest (Ha)	*Cupressus lusitanica* (Ha)	*Pinus patula* (Ha)
Kericho	990	24,111.90	594	297
Kerisoi	2,346.10	5,020.70	1,408	704
Malagat	804.5	6,217.90	483	241
Londiani	1,983.10	7,032.45	1,190	595
Makutano	3,561.84	1,912.25	2,137	1,069
Tendeno	391.55	1,950.10	235	117
Sorget	3,355.30	3,501.30	2,013	1,007
Total	13,432.40	49,746.60	8,059	4,030

Source: Kenya Forest Service, 2019

The main source of saw lumber in Kericho is Makutano, Sorget and Kerisoi Forest Stations.

2.3.5 Equipment and machinery in sawmilling

Equipment and machinery deployed in the Sawmilling industries are primarily meant to replace the human workforce that was initially deployed in the process. The idea is to make the process faster, cheaper, neater and more efficient. Although there have been several negative effects like increased injuries (Segun & Yahaya, 2010) and noise pollution (D'Antonio, D'Antonio, Evangelista, & Doddato, 2013) among others, the overall assessment of deploying machineries in Sawmilling has been positive.

There are several equipment and machinery type used in the Sawmilling process that include stakers, log turners, conveyors, debarkers, board feeders, band saws, gang saws, Chainsaws, edgers, chippers and planers (GlobalSpec, 2018).

2.3.5.1 Gang saws

A gang saw is a type of power saw that makes several cuts simultaneously. Typically, a gang saw operates as a saw and conveyor, pulling logs across its blades to cut an entire section into planks with one pass.

Plate 2.2: A Panel Gang Rip Saw

One of the main advantages of a gang saw is that it is capable of higher production than a horizontal band saw. Its production capacity is high when compared with most saws, (Haghshenas, 2019).

2.3.5.2 Band saws

A band saw is a powered saw with a long, sharp blade consisting of a continuous band of toothed metal stretched between two or more wheels to cut material.

Plate 2.2: A band saw (Wood-mizer, 2018)

Band saws are mostly preferred due to their ability to create faster and more accurate wood cuts as compared to other saw types. They are also not only flexible but also provide precise cuts. The smaller kerfs in band saws improve recovery during lumber conversion. They are used principally in woodworking and lumbering, but may cut a variety of materials. Shaping band saw' advantages include uniform cutting action as a result of an evenly distributed tooth load, and the ability to cut irregular or curved shapes, (Nagendra, 2020). When compared to the jigsaw, this saw has the ability to cut faster and not only do they minimize wastage in lumber recovery but are also one of the safest saws during the process of Sawmilling, (Nagendra, 2020).

2.3.5.3 Chainsaws

Chainsaws are portable saws that have their teeth attached to a rotating chain and powered by mechanical engines. When the saw is powered up, the teeth rotate with speed in a circular motion that causes them to cut into wood. Figure 2.4 below shows an image of a chainsaw at work.

Plate 2.3: A Chainsaw Converting a Log into Lumber (Wood-mizer, 2018)

Chainsaws have replaced the traditional axes that were manually used for felling trees. In Kenya, they are the main saws used to fell trees for commercial purposes. The origin of this saw idea is believed to be from Germany dating back to 1830s (Lennox, 2006) the first patent for the saw was however secured in 1905 (United States Patent No. 780,476) whereas the first movable one was patented by a Canadian in 1918 (Wardrop, 1976). When the portable chainsaw's patent expired, other developers came into play and the focus of improvement became engine power, propulsion type and the weight and size of the chainsaws. The first electric powered chainsaw was thus invented in 1926 and the first fuel powered chainsaw invented in 1927 (Wardrop, 1976).

The chainsaws have now simplified some steps in the process of Sawmilling. The labour requirement in tree felling and manipulation has also reduced drastically. The ever-reducing weight of these machines has made them easy to use and handle. As opposed to the old days where at least two people were required for handling, the modern day chainsaws are usually operated by a single person.

2.3.5.4 Circular saws

Circular saws were predominantly used for crosscutting logs into the required lengths, (Krilek, 2014). However, some Sawmills utilize circular saws to converts logs into lumber. This however comes at a cost as the saw has a wide kerf thus leading to high wastages, (Krilek, 2014). This saw type is normally connected to a motor that provides the rotating force. The main advantage of the circular saw is its efficiency in that the saw is ready to cut whenever the blade is in motion. Some circular saws are portable thus can be moved from place to place depending on the availability of raw materials and market, (Krilek, 2014).

Plate 2.4: A Circular Saw

2.3.5.5 Frame saws

Most Sawmills also prefer frame saws due to their convenience. A frame saw is a type of saw which consists of a relatively narrow and flexible blade held under tension within a rectangular frame. They are used for cutting wood. The blade is held perpendicular to the plane of the frame, so that the material being cut passes through the center of the frame. (Juvonen, 2020)

Plate 2.5: A Frame Saw Cutting Through a Log.

The main advantage of frame saws is that the blades are relatively long and thus permit faster cutting. Frame saws also offer flexibility in their installation as they require little space to mount, (Juvonen, 2020). The production capacity of frame saws is also relatively high as compared to band saws.

2.3.5.6 Narrow band saws

The Narrow Band Saw is a saw in the form of a continuous metal band with teeth on one side. They are one of the most frequently used machines in furniture making workshops. Though it is used most effectively on wood, it can also be used to cut other materials, like steel, acrylic, foam and boards. The blade is suspended over two metal wheels and revolves in a continuous cutting motion. As the direction of the blade is always downward, there is no danger of kickback, i.e. the wood being forced back at the operator. The band saws unique feature is that the work piece can be rotated around the blade and this enables curve cutting. The band saw blade produces a thin kerf and can cut thick stock with minimum power making it an extremely versatile machine with good lumber recoveries.

2.3.5.7 Wood-mizers

Wood-mizer is a derivative name for wood handling machines developed by the Indianapolis Company called Wood-mizer. This company was founded in 1982. It has two founders namely Don Laskowski and Dan Tukulve (Wood-mizer, 2018). The company has a multinational outlook but has its headquarters in the Indiana State in the USA. The founders were interested in simplifying the process of logs to planks conversion, which was conventionally handled by several people and took exceptionally long (Wood-mizer, 2018).

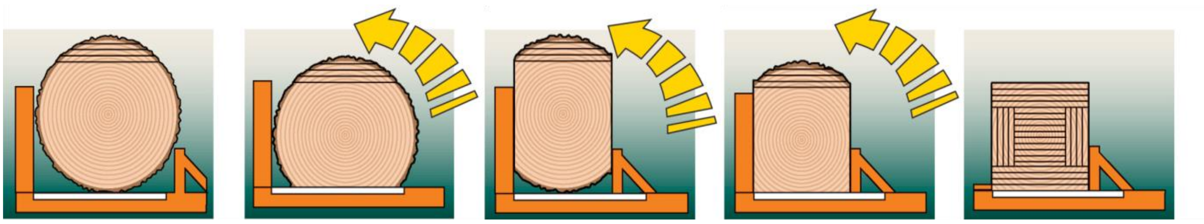

Figure 2.2: The Log to Planks Conversion Process

The conventional tools used required a lot of handling care and were prone to catastrophic accidents. Sawmills were bulky and wood had to be transported to the point of sawing. The Wood-mizer Company focused on developing portable Sawmills that could be carried to the point of tree felling to simplify the process of Sawmilling. This study was focused on three of the Wood-mizer portable Sawmills that are LT15, LT20 and LT40 which area discussed in the following subsections. These portable Sawmills generally follow the same pattern of converting logs into lumber. The first cuts are generally made at the top of the log after which the log is rotated 180 degrees to ensure that the flat top becomes the stable base of the log after the rotation. Another cut is once again made at the top of the log. The idea is to extract square or triangular cants from the logs. The log is therefore turned 90 degrees for cutting and the remaining side eventually squared out. The cant is then systematically cut into planks while strategically rotating the cant around the sawing rail (Wood-mizer, 2018).

2.3.5.7.1 Wood-mizer LT15 portable machine

This is the least sophisticated of the three portable machines that were of interest to this study. Most of the processes that include logs loading and blade movement are manual and require additional labour to be done. The following is an image of Wood-mizer LT15 in action.

Plate 2.6: Wood-mizer LT15 Converting a Log into Lumber

This machine, like the other two can be powered by diesel, petrol or electricity. It can handle logs of a maximum diameter of 72 Centimeters and a maximum log length of 234 Centimeters. As can be seen in Plate 2.1 above, (Dormer Sawmill, 2019), as a result of its manual nature, the production capacity is generally low in comparison with the other two portable Wood-mizers. The skidded logs must be loaded onto the sawing rail of the machine manually thus requiring extra energy. The blade head is also moved along the log during the cutting process manually as well. The turning of the log on the sawing rail is done manually using a cant hook (Wood-mizer, 2018).

2.3.5.7.2 Wood-mizer LT20 portable machine

This is an improvement of Wood-mizer LT15. It has improved portability, improved control panel and an automatic log loader in most models (Wood-mizer, 2018). Plate 2.2 shows an image of Wood-mizer LT20 at work.

Plate 2.7: Wood-mizer LT20 Converting a Log into Lumber

2.3.5.7.3 Wood-mizer LT40 portable machine

This is an improvement to both the Wood-mizer LT15 and the Wood-mizer LT20. The main improvement as can be seen in plate 2.2 above (Timsos Sawmill, 2019), is the level of automation that has been achieved. There is automatic log loading, automatic log rotation, automatic blade movement and even assisted lumber return. There are several extensions that can be made that include extending the log rail for longer logs and a number of customizations that can be added before shipping from the developers (Wood-mizer, 2018). Plate 2.3 Shows a Wood-mizer LT40 at Work, (Lel Timber Sawmill, 2019).

Plate 2.8: Wood-mizer LT40 Converting a Log into Lumber

2.3.5.7.4 Wood-mizer LT70 portable machine

This is Wood-mizer machine fully-loaded with high-production features, the LT70 super hydraulic portable sawmill is engineered for sawyers that demand high-production sawing from a portable sawmill. The LT70 is fully-loaded with engine-powered hydraulic log handling and head controls, pedestal remote control station with joystick controls, deluxe board return with out-feed table, debarker, LubeMizer blade lubrication, and more. The LT70 super hydraulic is completely portable and easy to be moved with a standard single axle trailer and electric brakes. Six fine-adjust outriggers allow for quick set-up and precise leveling of the bed prior to sawing. The patented open side of the LT70 hydraulic saw head allows for minimal leveling during set-up, easy off-bearing with the trapezoid shaped bed, and sawing of odd shaped logs.

Plate 2.9: Wood-mizer LT70 Converting a Log into Lumber (Wood-mizer, 2018)

2.3.6 Conversion efficiency

Lumber Conversion efficiency was used to compare the usefulness of different machines and methods in Sawmilling. There are many way of determining the lumber conversion efficiency during Sawmilling. The conversion efficiency of logs into lumber is commonly expressed as lumber recovery factor (LRF) or as over run. Lumber recovery factor is the nominal board feet of lumber divided by the cubic volume of logs. Over run is the nominal lumber board feet divided by the board feet log scale. Over run is a relatively poor measure of conversion efficiency because there is little relation between the log scale and the potential lumber volume recovery, and because of differences in board footage for the same log among the various log scales, LRF is a more direct measure of conversion efficiency (Wenger, 1984).

There are several factors that influence the LRF. Some of these factors are log diameter, log length, log quality, the sawing variation, sawing methods and kerf width (Steele, 1984). There are several methods of estimating the conversion efficiency that range from sophisticated ones

(Ministry of Forestry, Land & NRO, 2014) and an array of models (Wade, Bullard, Steele, & Araman, 1992). Lumber recovery efficiency is widely used as a measure of assessing the performance of any Sawmills (Babatola, Akindeni & Olaniran, 2012). For the purpose of this study, lumber Conversion efficiency for Wood-mizer LT15, LT20 and LT40 was determined through a Survey as per the operational setups (descriptive).

2.3.7 Recovery rate

Lumber recovery in Sawmilling was determined by a confusing interaction of several variables. Since no two Sawmills are alike, the variables that influence lumber recovery are seldom the same from one Sawmill to another. Factors like Log diameter, length, taper, and quality, Kerf width, Sawing variation, rough green-lumber size, Product mix, decision making by Sawmill personnel, Condition and maintenance of mill equipment and Sawing method affect lumber recovery. Lumber recovery efficiency is widely used as a measure of assessing the performance of any machine. The mode of estimation is by dividing the total lumber product in cubic meters by total log input volume. However, this does not take into account the size, quality or grade of the log in question. Log size, quality or grade and length are also important factors to be considered in lumber recovery, (Steele, 1984). Therefore, the lumber recovery factor is the percentage of sound lumber produced from a log (Alviar, 1993). The lumber recovery rate of logs range between 40 and 50 % as reported by (Alviar, 1993). As seen from Table 2.3 below, there has been huge losses incurred as a result of inefficient lumber conversion technologies, (Wanleys, 2013).

Table 2.3

Recoverable Supply Available for the Market

Item	Lumber					Poles	Wood fuel		Total
	Saw mills $\times10^6$	Mobile saws $\times10^6$	Total sawn wood $\times10^6$	Others (pulp, ply, carvings) $\times10^6$	Total Lumber $\times10^6$	$\times10^6$	Fire wood $\times10^6$	Charcoal $\times10^6$	$\times10^6$
National Potential Supply (m^3)	4.5	2.45	7.01	0.346	7.36	3.02	13.65	7.35	31.37
Recovery rates (%)	32	25		95		95	95	16	
Available National Supply (m^3)	1.45	0.61	2.07	0.328	2.40	2.87	12.97	1.17	19.42

Source: (Ototo *et al*, 2018)

2.3.8 Production capacity

There are two types of production capacities that were of interest to this study: one is the production capacity of Sawmills and two is the production capacity of the Wood-mizer LT15, Wood-mizer LT20 and Wood-mizer LT40. The lumber production rate for the Wood-mizer machines is estimated to be 0.75m^3/hour for Wood-mizer LT15, 0.95m^3/hour for Wood-mizer LT20 and 1.3m^3/hour for Wood-mizer LT40, (Wood-mizer, 2018).Capacity can be seen as the maximum output per given measure of time that a given machine or Sawmill can produce. This study focused on the production capacity of the machines. Several factors can affect production capacity of a given machine. These include raw material characteristics and availability, labour quality and availability, and the storage capacity. Increasing Sawmill production capacity is critical as it decreases per-unit cost and improve profit margins, helps gain labour economies of scale (particularly useful for Sawmills with challenges keeping skilled staff), potentially decrease energy costs, enable better customer service as Sawmills with increased capacity can respond to large orders and make more products to maintain and increase sales. In addition, another advantage of higher production capacities is that costs can be spread over larger quantities of goods. In the long-run, it is considered that all inputs to a firm are variable and that the period of time is sufficient to permit adjustment in scale or size of operation. This being so, reason dictates that adjustments in firm or plant size over time will be in the direction of what is considered to be an optimum quantity or range of product output.

2.4 Conceptual Framework

This study focused on the concept of resource sustainability. Instead of just focusing on protection and conservation as the main propellers of sustainable use, the study went further to include the extracted resources' recovery and efficiency in utilization as a major proponent of the cycle of sustainability. The concept thus becomes as simple as prepositioning that the slower the extracted resource is utilized through efficiency in processing, the longer the extracted resource lasts. The longer the extracted resource lasts, the lower the frequency of extracting from the resource pool. The lower the frequency of extraction from the pool, the longer the time the resource takes until depletion. If the resource is renewable, it thus follows that there shall be longer inter extraction intervals to allow for the healing and regeneration of the resource pool. Tree species which were of interest in this study are *Cupressus lusitanica* and *Pinus patula*. The two species' rotation age is thirty years.

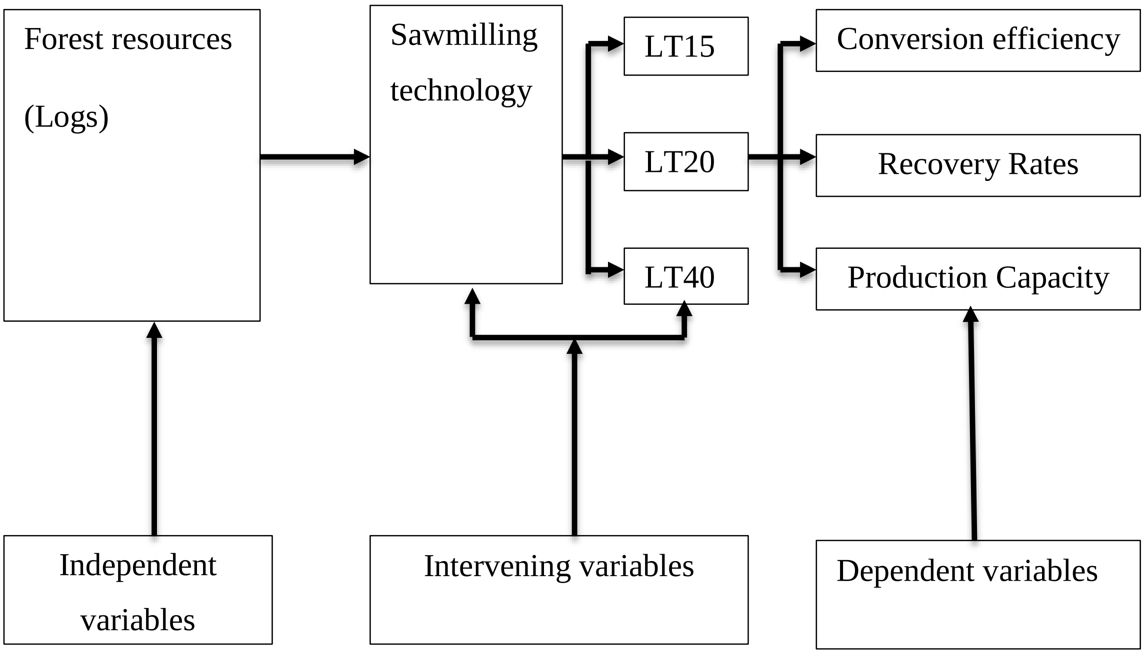

Figure 2.3: Conceptual framework showing Interacting Variables

2.5 Identification of Knowledge Gaps

The conservation of forests is paramount due to the influence forests have on climate, landform and soil composition. Each forest type has its own uniqueness and together these forests complement one another and perform the various socio-economic, ecological, environmental, cultural and spiritual functions. The knowledge gap that this study intended to fill was the extension of conservation effort beyond the resource protection paradigm. The concept of sustainability seems to be limited in scope to the regenerative extraction where the harvest is balanced by the regrowth (SERI, 2009). Maybe when efficiently utilized, the frequency of extraction can be drastically reduced and everything held constant, the resource, even without regeneration can last a little longer. This study therefore was a step into the knowledge gap that focuses in efficiency for sustainability (SERI, 2009). Therefore, the study intended to fill the following gaps:

- A gap linking primary conservation efforts and efficiency in utilization of the same resources.
- A gap about details on the longevity of the extracted resources.
- A gap in data on lumber conversion efficiency, recovery rates and production capacities of *Cupressus lusitanica* and *Pinus patula* lumber in Kericho County.
- A gap on knowledge on the current status of sawmilling in Kericho County.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes the research design, study location, target population, sampling procedures that were used, data collection instruments, data collection procedures, data analysis and presentation procedures and the ethical considerations related to this study.

3.2 Research Design

This study followed both the experimental and survey research designs to collect data. First, a survey was conducted to establish the respondents' reaction and opinion on Wood-mizer Machines to evaluate their conversion efficiency and the status of sawmilling in Kericho County. Through simple random sampling on the respondents, open ended questionnaires were used to collect data.

In addition, an experiment was set up through a Quasi-experimental design to evaluate lumber recovery rates and production capacity in 3 selected Sawmills. Logs delivered to the log yards were randomly sampled and placed in 10 diameter classes (10-60cm). In each diameter class, 4 logs of both *C. lusitanica* and *P. patula* tree species were selected and their individual volumes computed. The logs were then converted using selected Wood-mizer machines and measurements of resultant products and residues taken to evaluate recovery rates and production capacity. This was repeated for all diameter classes for replication.

3.3 Location of Study

The study was conducted in Kericho County which covers 2,479km^2 and has code number 35 (Constitution of Kenya, 2010) and has its headquarters in Kericho town. Kericho experiences a warm and temperate climate. The variation in the precipitation between the driest and wettest months is 185 mm. The County records significant rainfall throughout the year, with average annual rainfall standing at 1,735 mm. The rainfall pattern is such that the central part of the County, where tea is grown, receives the highest rainfall of about 2,125mm p.a, while the lower parts of Soin and parts of Kipkelion receive the least amount of rainfall of 1,400 mm p.a. The county experiences two rainy seasons: the long rainy season between April and June and the short rainy season between October and December. During the year, the average temperatures range between 20.9^{0}C and 25.1^{0}C. With a tree cover of 23.23%, (Kenya Forest Service, 2021) the County is one of the greenest in the Country. The County is home to 63,179 hectares of Mau Forest Complex, the biggest closed-canopy forest ecosystem and water catchment in Kenya. Out of this area, 13,432.40 hectares fall under industrial plantations with the annual allowable cut being 447.70 hectares. Figure 3.1 shows the Kericho County in relation to the map of Kenya, (Kenya National Bureau of Statistics, 2018).

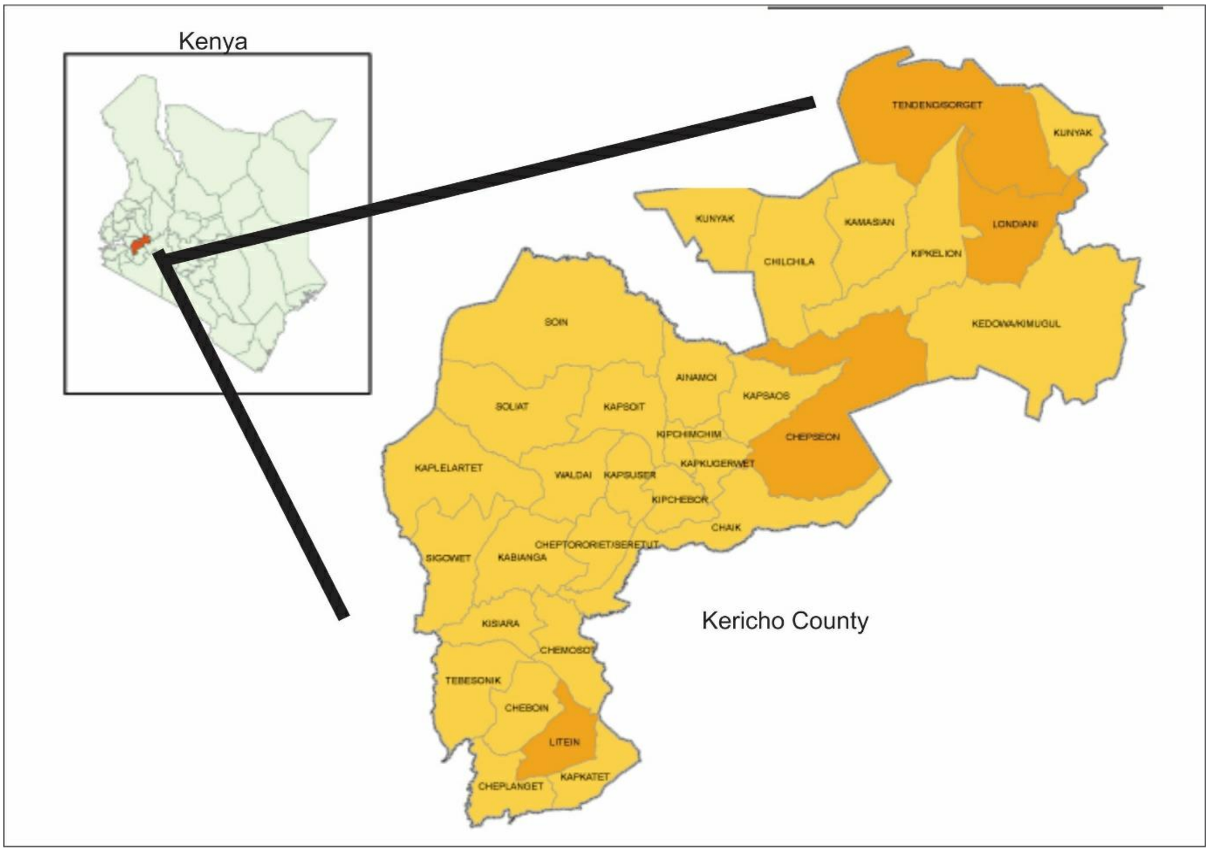

Figure 3.1: Map of Kericho County, Kenya

3.3.1 Study sites

This study was carried out in three selected Sawmills in Kericho County using Wood-mizer machines as reported in Table 3.1

These Sawmills have been pre-qualified and licensed by Kenya Forest Service (KFS) and therefore meet the required operating standards, as per the harvesting rules of 2009 to source forest materials from Kenyan Government forests.

Table 3.1

Selected Sawmills and their Location

Name of Sawmill	Type of Sawmill machinery	Location
Lel Timber	LT40 Wood-mizer	Kericho town
Timsos	LT20 Wood-mizer	Kericho town
Dormer	LT15 Wood-mizer	Londiani

Figure 3.2 shows the location of the three sawmills, (Source: researcher).

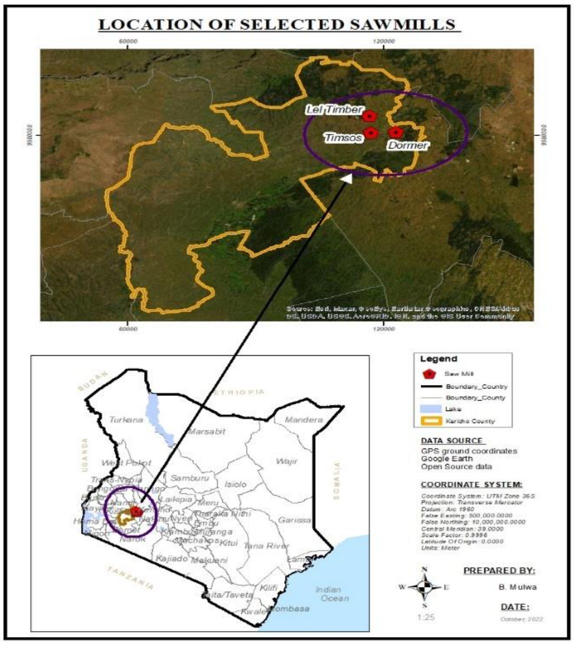

Figure 3.2: Location of the three selected sawmills

3.4 Study Population

A sample size of three (3) Sawmills for experimental and forty seven (47) Sawmills for survey research were selected for study from a population of fifty four (54) registered Sawmills in the County. The study then targeted the two commonly grown tree species in Kericho County; *Cupressus lusitanica* and *Pinus patula* round logs of top diameter class range 10-60cm delivered to the log yard of each of the three selected Sawmills. These logs were sourced from private tree growers in Kericho County. This diameter range is optimal for saw logs in Kenya.

3.5 Sample Size and Sampling Procedures

This section describes in details how the sample size of Sawmills and logs was determined and outlines how each specific Sawmill and log was selected as part of the sample.

3.5.1 Sample logs for empirical study

Three Sawmills (Lel Timber, Timsos and Dormer) were purposively selected based on functionality, accessibility and presence of the Wood-mizer machine of interest. Twelve (12) logs of various lengths of both *Cupressus lusitanica* and *Pinus patula* tree species were chosen randomly from each of the top diameter classes (10-14cm, 15-19cm, 20-24cm, 25-29cm, 30-34cm, 35-39cm, 40-44cm, 45-49cm, 50-54cm and 55-59cm). Ten classes were considered based on the ratio between the range of the diameters and the expected number of classes. A total of 120 logs were therefore sampled from both *C. lusitanica* and *P. patula* combined as shown in table 3.2. Twelve (12) logs of each diameter class of the two tree species (*C. lusitanica* and *P. patula*) were then converted using the three different Wood-mizer machines ((LT15, LT20 and LT40) respectively as shown in Figure 3.3.

3.5.2 Experiments

Logs of various lengths were sampled randomly, converted into lumber and the amount of resultant products and residues evaluated. The time taken to complete each task was also measured as reported. Figure 3.3 shoes the experimental setup.

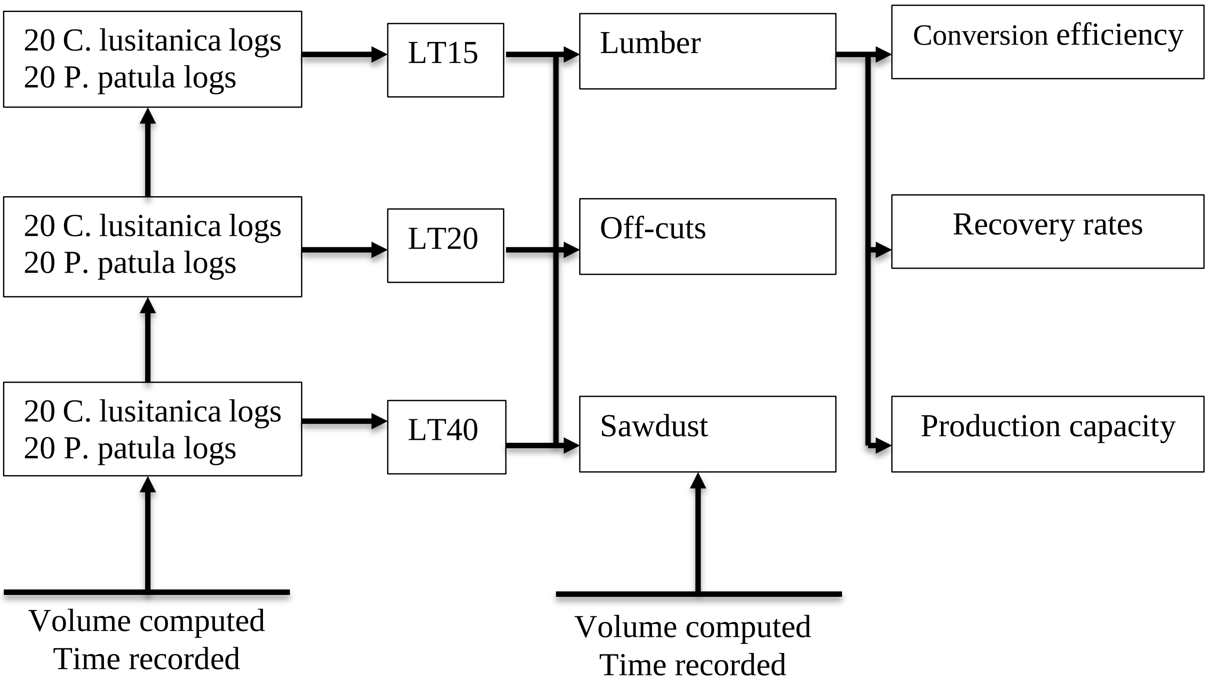

Figure 3.3: Experimental Setup for log conversion

The distribution of sampled logs is as shown in Table 3.2

Table 3.2

Distribution of sampled logs by Sawmill in the selected Sawmills

Log Species	Diameter class (cm)	No. of Logs per Sawmill		
		Lel Timber	Timsos	Dormer
C. lusitanica	10-14	2	2	2
	15-19	2	2	2
	20-24	2	2	2
	25-29	2	2	2
	30-34	2	2	2
	35-39	2	2	2
	40-44	2	2	2
	45-49	2	2	2
	50-54	2	2	2
	55-59	2	2	2
P. patula	10-14	2	2	2
	15-19	2	2	2
	20-24	2	2	2
	25-29	2	2	2
	30-34	2	2	2
	35-39	2	2	2
	40-44	2	2	2
	45-49	2	2	2
	50-54	2	2	2
	55-59	2	2	2
Total		40	40	40

3.5.3 Sample sawmills for social survey

The sample size was selected based on the Singh et al., (2014) sample estimation methods. The size of the respondents was computed at a confidence interval of 95% and a standard deviation of 0.05. The size of respondents was computed as follows:

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

Where;

e- the level of statistical significant set (0.05).

N- the population size of the study segment.

n- the sample size of registered Sawmills.

A sample size of 47 Sawmills across the County were studied from a total of 54 through simple random sampling without replacement. In each Sawmill, personal interviews with two operators were carried out to ascertain the lumber conversion efficiency of machines used.

3.6 Data Collection Instruments

3.6.1. Validity of the instruments

All equipment (Diameter tapes, linear tapes and rulers) that were used for measurements were calibrated or confirmed to be in good condition. The Wood-mizer machines were accessed from pre-qualified Sawmillers by the Kenya Forest Service. Diameter tapes and linear tapes were sourced from the Kenya Forestry College.

3.6.2 Reliability of the instruments

There were four logs selected per diameter class per species. The same machine converted logs of various diameter classes for results comparisons. Consistency of results from the diameter classes indicated reliability. So as to ensure reliability, the questionnaire was pre-tested in a pilot study of thirty respondents. Then the questionnaires and interview were applied to selected respondents in the study area. A high reliability of 0.76 was obtained by estimating consistency in the responses when questionnaires were administered repeatedly. For exploratory and pilot studies, a reliability level of (0.7 to 0.9) is considered as high reliability (Taherdoost, 2016).

3.7 Data Collection Procedures

Data were collected during the official working hours (between 0800hrs and 1700hrs) and entered into predetermined sheets.

3.7.1 Survey data

3.7.1.1 Status of sawmilling in Kericho County

To assess the status of sawmilling in the County, face to face interviews were carried out to determine the of Sawmills' location and year of establishment, Species composition of logs delivered to the Sawmills, number of machines for log conversion per Sawmill, Sawmill workforce, Sawmill daily working hours and Wood-mizer machines present.

3.7.1.2 Estimating conversion efficiency

In the assessment of lumber conversion efficiency, face to face interviews were carried out with key informants, mainly Sawmill owners and their Sawmilling crew. They were asked to state the ability of each Wood-mizer machine to convert logs into lumber well, successfully, and with minimum waste. They were further probed on the level of performance of each machine in relation to usage of the least amount of inputs to achieve the highest amount of output. Three components of efficiency namely inputs intake, ease of conversion and quantity of outputs were probed. To investigate levels of input intake, the study investigated the volume of logs that each Wood-mizer machine converts into lumber using through and through sawing method. To examine ease of operation, the level of simplicity in operating the machines without much difficulty or effort was probed. In assessment of quantity of lumber produced, the respondents were asked to rate each machine based on the volumes of lumber converted over time. The respondents were asked to rank the lumber conversion efficiency of each machine as low, moderate, or high.

3.7.2 Experimental data

3.7.2.1 Estimating lumber recovery

To estimate lumber recovery rate, an experimental set up was conducted in the 3 selected Sawmills using the various Wood-mizer machines (LT15 in Dormer Sawmill, LT20 in Timsos Sawmill and LT40 in Lel Timber Sawmill). Log measurements were taken to ascertain their volumes, then converted into lumber with the volume (m^3) and the number of the lumber pieces obtained being recorded and residues quantified in order to determine the percentage of lumber recovery. Various studies report that the lumber recovery ranges between 40 and 50 % in different types of Sawmilling machines Wood-mizers included, (Alviar, 1993). The interpretation of this is that 50 – 60 % of the log volume ends up as waste usually in the form of sawdust, edges, shavings and slabs.

There are several models of representing the lumber recovery. Lumber produced from each diameter class, sawing method pattern and tree species logs was evaluated according to Antobre (2010).

$$Recovery\ rate = \frac{Total\ volume\ of\ lumber\ produced\ (m^3)}{Total\ volume\ of\ logs\ used\ (m^3)} * 100 \ldots\ldots\ldots\ldots\ldots Equation\ 2$$

Log Volume estimation was computed using Huber's formula:

$$V = L * gmid \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \ldots Equation\ 3$$

Where;

V = Volume of log in cubic meters,

L = Length of log in meters (various).

Gmid = Cross-sectional area at midpoint

Volume of lumber (V_1), was computed as follows;

$$V1 = L * W * T * N \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \ldots Equation\ 4$$

Where;

V_1 = Volume of lumber in cubic meters

L = Length of lumber in meters,

W = Width of lumber in meters,

T = Thickness of lumber in meters and,

N = Total number of equal pieces from each log.

Volume of sawdust generated was computed as described below, (Babatola, et al., 2012).

$$Vsd = b.1 \int_{1}^{n} w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. Equation\ 5$$

Where;

*V*sd – Volume turned to dust, m^3

b – Kerf of the saw blade

l – Length of the log, m

w – Width of each plank at the point of cut, m

Volume of off-cuts was computed as follows, (Source: Researcher);

$$Voff = Vl - (Vt + Vsd) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; Equation\ 6$$

Where;

Voff – Volume of offcuts

Vl – Volume of log

Vt – Total volume of lumber

Vsd – Volume of sawdust

The diameters of logs were measured using diameter tapes. Top and bottom diameter of the log were measured and used to determine the average diameter used in log volume computation, (Phillip, 1994). Lumber lengths were measured using linear tapes. A ruler was used to estimate the thickness of the sawn lumber output. These measurements were taken for each machine under study separately.

3.7.2.2 Estimating lumber production capacity

The lumber production capacity was determined empirically. At the start of lumber conversion, initial time (t_1) was recorded. Consequently, final time (t_2) was recorded at the end of lumber conversion. With volumes of lumber and the time input, production capacity was estimated using the following production rate formula (Source: Researcher):

$$P = \frac{V}{t2 - t1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; Equation\ 7$$

Whereby;

P = Lumber Production rate (m^3/hour)

V = the total volume of lumber produced in cubic meters,

t_1 = initial time in hours and;

t_2 = the final times in hours.

Time measurement was taken using a stopwatch. An 8 hour day production capacity was then calculated by multiplying the production rate by time taken. This was done separately for all the three machines under investigation.

3.8 Data Analysis and Presentation

3.8.1 Conversion efficiency

The survey data on assessment of lumber conversion efficiency were cleaned to remove outliers, sorted, entered to MS. Excel and SPSS software and systematically analyzed. The derived data were presented in Tables 4.10, 4.11, 4.12 and 4.13.

3.8.2 Recovery rate

Data on the assessment of recovery rates was entered into SPSS software and analysis done with the help of statistical package SPSS for measures of centre. Analyzed data was presented in figures 4.2 and 4.3 and Tables.

3.8.3 Production capacity

The data on volumes for assessing production capacity were entered in Microsoft Excel for every Wood-mizer machine and lumber species. Log volumes, lumber volumes and the time input were presented in Tables. Lumber production per hour was used to calculate the lumber production capacity per day with 8 working hours.

3.9 Ethical Considerations

A research permit was granted by the National Commission for Science, Technology and Invention (NACOSTI) and a local research notification made to Kericho County where the study took place. Also, an introductory letter from the university was attached to the questionnaires during data collection as a proof for authorization. The respondents were promptly informed about their freedom to participate or not participate in the study without any form of coercion and intimidation. A proper introduction of the researcher, the topic of interest and the rights of the respondents were clearly stated.

The study also considered the fact that Sawmills are in competition with each other and some of the information that the study obtained could potentially be disadvantageous to or catalytic to the activities of some of the Sawmills. With this in mind, there was clearly guarded secrecy and anonymity of the respondents and data obtained.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents results on the Sawmills' location and year of establishment, Species composition of logs delivered to the Sawmills, number of machines for log conversion per Sawmill, Sawmill workforce, Sawmill daily working hours and Wood-mizer machines present. The results on conversion efficiency, recovery rates and production capacity for Wood-mizers; LT15, LT20 and LT40 are also presented and discussed.

4.2 Status of Sawmills in Kericho County

4.2.1 Location of sawmills in Kericho County

Although there are cases of unregistered Sawmills in the County, the study identified a total of 54 registered and prequalified Sawmills. Out of these Sawmills, four of them were large scale, 12 were medium scale and the rest (38) were small scale. Table 4.1 presents the distribution of Sawmills in Kericho County.

Table 4.1

Location of Sawmills in Kericho County

	Location	Number	Percentage (%)
1	Kericho Town	16	30
2	Londiani	12	22
3	Kerisoi	7	13
4	Malagat	6	11
5	Sorget	6	11
6	Makutano	4	7
7	Tendeno	2	4
8	Chesinende	1	2
	TOTAL	54	100

The majority of the Sawmills are concentrated around Kericho town and Londiani at 30% and 22% respectively. The main factors considered in siting Sawmills in Kericho County are: closeness to raw materials, availability of market demand, availability of machinery and transport, availability of labour and policies that were in play during the time of establishment (Callaway, 2010). This explains why Kericho town and Londiani had the highest number of Sawmills established. Whereas there was demand for finished wood products in Kericho town, the availability of raw materials is high in Londiani.

Locations like Tendeno and Chesinende despite having raw materials, had low demand since Sawmill products required additional transport to the market. It is difficult to find Sawmill experts in locations that are far from settlement areas. Firms planning to locate forest products manufacturing plants would be concerned with the availability and cost of raw material, labour and utilities; the location of markets and the transport linkages (China Ministry of Commerce, 2013). This is why Tendeno and Chesinende had 2 and 1 Sawmills respectively.

4.2.2 Establishment of sawmills in Kericho County

The age of Sawmills in the County is as shown in Table 4.2.

Table 4.2

Age of Sawmills in Kericho County

	Age of Sawmills (Years)	Number	Percentage (%)
1	Less than 10	5	10.6
2	More than 10	42	89.4
	Total	47	100

From the data collected, 5 out of 47 (10.6%) of the registered sampled Sawmills have been in operation for less than 10 years whereas 42 out of 47 (89.4%) of the Sawmills have been in operation for more than 10 years. These include all the large-scale Sawmills in the Study area.

The relatively newest Sawmills in the County were officially registered in 2015 after being vetted by Kenya Forest Service and allowed to register with the Government. The age of operation improves the experience of the Sawmilling crew which is a key factor in decision making during lumber recovery, (Steele, 1984). In 1999 the Government of Kenya suspended lumber harvesting in all government and other public forests. This logging ban was lifted in 2011 but was effective until 2012-2013. During this time, lumber supply from public plantations was heavily reduced, (Ministry of Forestry and Wildlife, 2016). The lifting of the logging ban led to additional Sawmills being registered with Kenya Forest Service as more people targeted to invest in the wide gap between demand and supply of forest products. The established Sawmills encountered the same problems relating to shortages in log supply when a consecutive logging moratorium was introduced in 2018.

4.2.3 Species composition of logs delivered to the Sawmills

Figure 4.1 shows the species composition of logs delivered to the log yards. Log species intake by Sawmills was found to be influenced by their availability and market specifications.

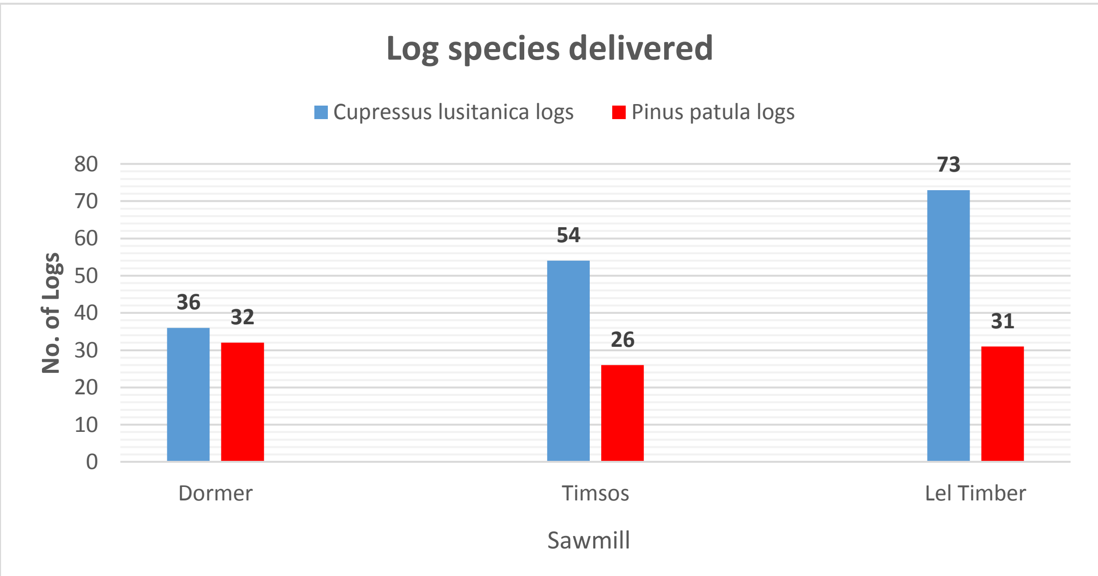

Figure 4.1: Species Composition of Logs Delivered to Sawmills in Kericho County

The study found that logs from *C. lusitanica* tree species were the most preferred followed by those from *P. patula.* At Dormer Sawmill, 53% of the logs delivered were of *C. lusitanica* species while 47% *P. patula.* In addition, 68% and 70% of *C. lusitanica* logs were delivered for Timsos and Lel timber Sawmills respectively in comparison to *P. patula* logs that were delivered at 32% and 30% respectively.

The choice of lumber species was largely influenced by the availability of raw materials within the County. The extensive advisory services offered by Kenya Forest Service officers in the choice of species during plantation establishment also had a bearing on the log species delivered to the Sawmills. Table 4.3 illustrates the Kenyan recommended species composition as per Forest Technical Orders, 1996 in comparison with logs delivered to Sawmills.

Table 4.3

KFS recommended Species Composition in Kenyan Forest Plantations in Comparison with Logs Delivered to Kericho County Sawmills, 2019

Species	Recommended proportion of total Plantation area (%)	Average species composition of logs delivered to the Sawmills (%)
Cypress	55-60	64
Pines	20-30	36
Eucalyptus	10	0
Other species	5-10	0

From Table 4.3 above, logs' species present in Sawmills was largely a factor of raw material availability rather than preference. In addition, *C. lusitanica* lumber was preferred due to better mechanical properties. There was no log recorded from species outside *C. lusitanica* and *P. patula.*

4.2.4 Number of machines for log conversion to lumber per Sawmill in Kericho County in 2019

To calculate the average production capacity for Sawmills, it was important to determine the number of machines that are available for use per Sawmill for log conversion to lumber. The results for this are as shown in Table 4.4.

Table 4.4

Number of Machines Available for Log Conversion per Sawmill in 2019

No. of sawing machines	Number of Sawmills	Percent (%)
1	35	74.4
2	7	14.9
3	4	8.5
4	1	2.1
Total	47	100

From table 4.4, 74.4% of the sampled Sawmills had only one machine that was primarily used for log conversion into lumber. The rest 25.6% had 2-4 machines. The later include large scale production Sawmills that require more machines to increase the daily lumber output. The highest number of machinery in Sawmills for log conversion was 4 (four) and accounted for 2.1% of the total Sawmills in Kericho. The presence of multiple machines not only improves the lumber output but also increase efficiency (Callaway, 2010).

Indeed the machines used primarily for log conversion in Kericho County are Wood-mizer, chainsaws, band saws, frame saws, crosscut saws and Circular saws. The number of lumber conversion machines in Sawmills depend on factors such as the availability of raw materials, the investment capacity and the scale of operation of the Sawmills (Bomba, *et al.,* 2016). Despite having a greater supply potential, the forest resources end up meeting less supply quantities due to inefficiency. The inefficiency is attributed to the use of the same machinery for different Sawmilling stages. Use of efficient technology is a problem for the small scale

Sawmills where logging and processing is labour intensive with most Sawmills using old inefficient machinery such as tractors and saws for milling, (Ministry of Environment, 2013).

4.2.5 Sawmills workforce in Kericho County

To accurately determine the production capacity of Sawmills in Kericho County, it was necessary to establish the average number of employees per Sawmill. It was also important to correlate the number of machines per Sawmill with the number of personnel operating the same machines. This correlation was important in determining whether the use of machines affects the hiring or firing of labour in the Sawmills.

Table 4.5

Number of Employees per Sawmill in Kericho County in 2019

Employees(No.)	Sawmills (%)
2	12.77
3	19.15
4	17.02
5	14.89
6	10.64
7	10.64
8	8.51
9	2.13
10	2.13
12	2.13
	100

It is observed in Table 4.5, that on an average, Sawmills in Kericho County have three (3) employees as it was the most frequent number of employees that was recorded in 19.15% of the total number of registered Sawmills. These results indicate that forest and wood processing sectors are generally characterized by under-capitalization, labour intensiveness and obsolete equipment (Antobre, 2010). The highest recorded number was 12 employees in 2.13 % of the registered Sawmills. In the wood sector, increased number of employees normally lead to higher productivity and efficiency (Ministry of Industrialization and Enterprise Development, 2015). While correlating the number of machines and the number of employees in the Sawmills, the descriptive statistic table 4.6 and the correlation Table 4.7 were generated using bivariate Pearson correlation analysis in SPSS.

Table 4.6

Machines Availability and Number of Employees in Kericho County in 2019

	Mean	Std. deviation	N
Machines per Sawmill	1.21	0.907	47
Employees per Sawmill	4.98	2.326	47

From Table 4.6, the average number of machines per Sawmill was 1 (rounded down from 1.21) whereas the average number of employees per Sawmill was 5. This meant that one machine required at least 4.12 employees (4.98/1.21). This also mean that machines availability in a given Sawmill was one of the factors that affected the decision of the management to hire or fire machine operating employees. This is key because if a machine can do a task currently done by humans, it will do it with greater precision, speed, and at a lower cost, (Mark, Robert and Jacob, 2019). The decision to add more employees to Sawmill depend strongly on the availability of machines in Sawmills. Sawmills with more machines had more employees whereas Sawmills with lesser machines had less employees. This is unlike in the Kenyan tea sector, where automation of tea harvesting through the introduction of mechanical tea harvesters significantly reduced labour costs by reducing man days employed per hectare thus directly impacting on employee turnover (Julius, 2020).

4.2.6 Sawmill daily work hours

The average number of hours Sawmills operate on a daily basis is important in the determination of their production capacity. The time each Sawmill opened in the day was also important for the assessment of production capacity. In an 8 hour day, Wood-mizer LT40 recorded the highest daily production capacity for both *C. lusitanica* and *P. patula* followed by LT20 and finally LT15

The data on the Sawmills' daily operating hours has been summarized in Table 4.7.

Table 4.7

Number of Hours Sawmills Operate in Kericho County

Operating hours /Day	Number of Sawmill	Percent (%)
5	2	4.3
6	3	6.4
7	9	19.1
8	20	42.6
9	12	25.5
12	1	2.1
Total	47	100

From Table 4.7, it is evident that most Sawmills (42.6%) in the County operate up to 8 hours each day. There were however Sawmills that operated for as low as 5 hours daily (4.3%) and as high as 12 hours daily (2.1%). In most of these Sawmills, there was continuous processing of logs and production of lumber during these times. Once the conversion machines like the Wood-mizers of interest were switched on, the machines would be on until the daily active hours are over and there would be continuous logs intake and lumber production during this active period. This particular information was useful in the assurance of accurate results when calculating the production capacity of the Wood-mizer machines of interest in this study. In Kenya, the normal working hours are forty eight hours during a six-day work week (8 hours per day) though certain types of workers may be required to work up to ten hours a day or sixty hours a week, (GOK, 2007).

4.2.6 Wood-mizer machines in Kericho County

This section gives information on the availability of Wood-mizer machines in the study area. The Sawmilling machines of interest were Wood-mizer LT15, Wood-mizer LT20 and Wood-mizer LT40.

Table 4.8

Wood-mizer Machines in Sawmills Operating in Kericho County

Type of Wood-mizer	Number Present	% of the total Wood-mizer machines
Wood-mizer LT15	18	60.0
Wood-mizer LT20	8	26.7
Wood-mizer LT40	4	13.3
Total	30	100

Sixty percent (60%) of the Wood-mizer machinery used in Kericho County are LT15, 26.7% were LT20 whereas 13.3% were LT40. This variation may have been as a result of the price range variation within these machines and could also be attributed to the relatively high cost of Wood-mizer machines (Wood-mizer, 2018). Wood-mizer LT15 currently costs USD 8,195, Wood-mizer LT20 costs USD 20,751 whereas Wood-mizer LT40 costs USD 27,860, (Wood-mizer, 2018). The results indicate that Sawmilling is cost demanding because while the right machine ought to be purchased that will give some advantage to the lumber output and ease of operation to the user, initial machine installation cost implications serve as a challenge (Ekhuemelo, 2015). There were only 2 Diesel powered Wood-mizer machines which were located in areas with no electricity power connectivity. Wood-mizer machines powered by electricity are easier to install, operate and maintain, (Wood-mizer, 2018).

4.3 Lumber Conversion Efficiency by Selected Wood-mizer Machines in Kericho County

Lumber conversion efficiencies for Wood-mizers LT15, LT20 and LT40 were assessed as per the operation setups (descriptive) of the Sawmills as presented below;

Table 4.9

Descriptive Wood-mizer Conversion Efficiencies in Kericho County, 2019

Wood-mizer Type	LT15	LT20	LT40
Efficiency	Mean	Mean	Mean
Poor	10.6	0	0
Low	48.3	22.2	12.6
Moderate	12.8	41.9	26.4
High	10.9	12.8	60.0

There was a non-response of 17.4%, 23.1% and 1.0% for Wood-mizers LT15, LT20, and LT40 respectively. This non-response was assumed to be due to lack of experience with the respective machines. It is observed that most respondents (48.3%) believed that the conversion efficiency of Wood-mizer LT15 was low in comparison with Wood-mizer LT20 and Wood-mizer LT40. This is because the LT15 is an entry-level mill that is capable of producing good results for sawyers who like converting lumber while minimizing their investment, (Wood-mizer, 2018). Wood-mizer LT 15 is also characterized by manual log handling that makes it labor intensive, (Wood-mizer, 2018).

On the other hand, 41.9% of respondents believed that Wood-mizer LT20 had generally moderate conversion efficiency. Unlike Wood-mizer LT15, there were no respondents that rated this particular Wood-mizer as poor. This could be so because, with more standard horsepower than the LT15 and the ability to saw unlimited log lengths, the LT20 is better suited to handle longer logs (Wood-mizer, 2018). However, 22.2% of the respondents rated this machine's conversion efficiency as moderate. This is attributed to the fact that, despite the differences in the initial installation costs between Wood-mizers LT15 and LT20, both machines are stationery and are characterized by manual log handling.

As also seen in table 4.9, sixty percent (60%) of the respondents rated the conversion efficiency of Wood-mizer LT40 as high. Indeed, it was observed that there was more preference for Wood-mizer LT40 than the other two machines (LT15 and LT20). This is attributed to the fact that Wood-mizer LT40 has a stationery control pannel as well as a hydraulic system for log handling which saves on time and labour when operating it (Wood-mizer, 2018). In addition Wood-mizer LT40 has an automatic log turning system that greatly enables the operator get the best log orientation for maximum lumber output.

4.4 Empirical Lumber Recovery Rates

Table 4.10 reports the empirical data on lumber recovery rates of Wood-mizer LT15, LT20 and LT40 machines in Kericho County. These data were based on experimental setup carried out in the Sawmills. In each experiment four (4) logs of *C. lusitanica* and *P. patula* were separately converted into lumber and recovery calculated as a percentage of the initial log volume. The recovery rates of the 60 logs each for both *C. lusitanica* and *P. patula* was added together and their means computed.

Table 4.10

Recovery Rates for C. lusitanica and P. patula in Different Sawmills

		Recovery Rates (%)		
Lumber Species	Wood-mizer Type	LT15	LT20	LT40
C. lusitanica	Mean	43.13	49.42	52.77
	Std. Dev (±)	10.52	15.35	12.38
P. patula	Mean	38.77	33.61	60.32
	Std. Dev(±)	6.07	4.82	15.41

4.4.1 Recovery rates for Wood-mizer LT15 machine

The average lumber recovery rate for *C. lusitanica* logs while using this machine was 43.1%. *P. patula* logs yielded a recovery rate of 38.8%. The low recovery rates recorded for Wood-mizer LT15 is explained by the fact that this machine operates on manual log handling and a mobile control center that can lead to fatigue of the Sawmilling crew hence poor decision making. In comparison with *P. patula, C. lusitanica* had the higher rate of recovery which is attributed to the chemical properties among *P. patula* logs among other factors (USSDA Forest Service, 2010).

4.4.2 Recovery rates for Wood-mizer LT20 machine

The average recovery rate for *C. lusitanica* was 49.4% while that for *P. patula* was 33.6%. The recovery rate of *C. lusitanica* logs was better than that of *P. patula* .This may have been as a result of the fact that *Pinus patula* trees emit a class of chemical called terpenes which is responsible for the trees' sticky resin and pine scent. This chemical reduces ease in workability and slows down the rate of lumber conversion by altering tensile strength and elastic modules, thus affecting decision making by the sawmilling crew, (Yang et al, 2020).

4.4.3 Recovery rates for Wood-mizer LT40 machine

Wood-mizer LT40 had the highest average recovery rate at 60.3% when converting *P. patula* logs and at 52.8% when converting *C. lusitanica* logs. This is attributed to the degree of automation of the machine compared to Wood-mizers LT15 and LT20. Increased automation reduces errors emanating from decision making by the Sawmilling crew, (Wood-mizer, 2018). As seen in Figure 4.2, the more the machine sophistication, the higher the recovery rates.

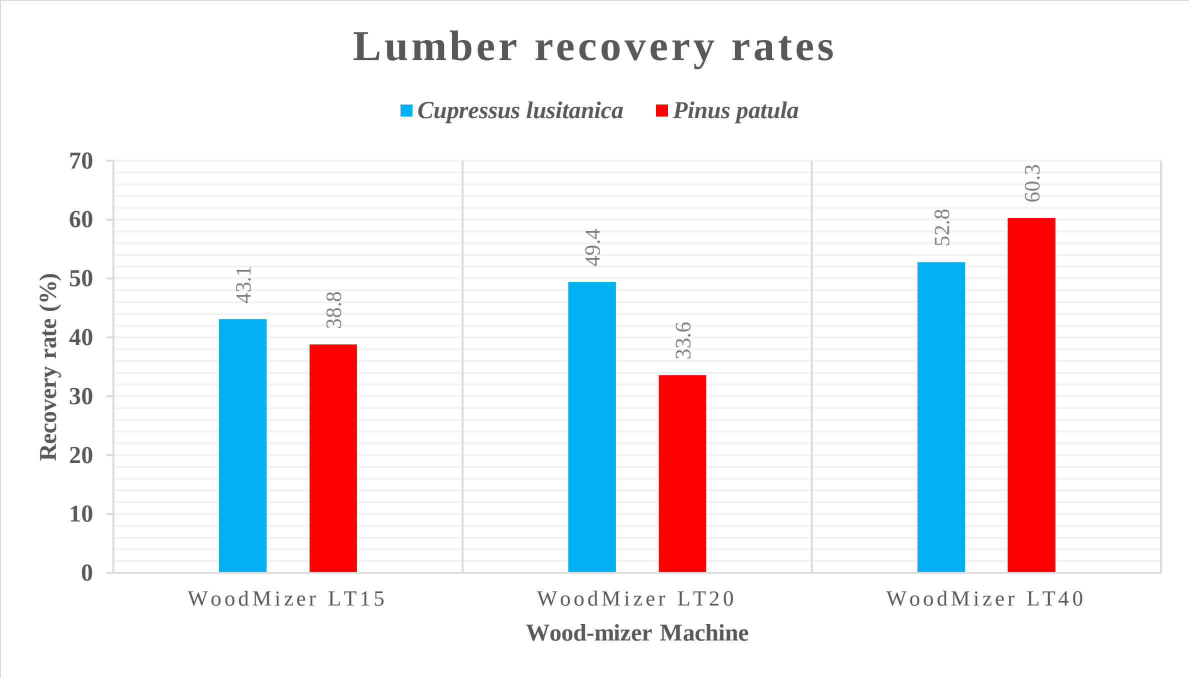

Figure 4.2: Recovery rates

4.4.4 Comparison of *Cupressus lusitanica* and *Pinus patula* Recovery Rates

C. lusitanica exhibited a better recovery rate than *P. patula* for Wood-mizers LT15 and LT20. This may have been as a result of the fact that *P. patula* trees emit a class of chemical called terpenes which is responsible for the trees' sticky resin and pine scent. This chemical reduces ease in workability and slows down the rate of lumber conversion by altering tensile strength and elastic modules, (Yang et al, 2020). Wood-mizer LT40 on the other hand showed different results where *P. patula* converted more efficiently than *C. lusitanica*. The increased sophistication in LT40 machine yields better results in less tapered logs (USSDA Forest Service, 2010). Similarly the increased level of automation in the Wood-mizer LT40 machine involving automatic log loading arms, an automatic log turner and a static control center contributes to its better performance (Wood-mizer, 2018).

C. lusitanica mechanical properties such as density, shear parallel to grain and tensile strength make it harder to convert into lumber than *P. patula,* however the presence of sticky resins in pines also serves as a hindering factor (Yang *et al.,* 2020).

4.4.5 Log diameter effect on recovery rates of Wood-mizer LT15, LT20 and LT40

The lumber recovery rates across different diameter classes of both *C. lusitanica* and *P. patula* logs are presented below in Table 4.11.

Table 4.11

Comparative Recovery Rates for Logs with Varying Sizes

Lumber Recovery (%) min and max						
Wood-mizer Type	LT15		LT20		LT40	
Species Diameter Class(cm)	*C. lusitanica*	*P. patula*	*C. lusitanica*	*P. patula*	*C. lusitanica*	*P. patula*
10-14	40	38	23	27	40	32
	48	31	12	27	42	41
15-19	31	58	60	25	44	39
	33	44	53	29	43	46
20-24	43	50	57	28	46	50
	42	38	55	31	27	56
25-29	46	42	34	32	48	56
	25	39	48	33	52	83
30-34	43	37	54	33	54	69
	36	34	74	34	57	76
35-39	44	36	50	35	59	75
	46	37	60	34	61	81
40-44	32	37	31	36	42	87
	48	40	62	37	62	64
45-49	29	34	45	35	68	53
	67	35	58	37	62	72
50-54	44	35	40	39	40	54
	49	35	67	41	67	53
55-59	60	37	42	40	69	58
	56	39	64	41	74	62
Average	43	39	49	34	53	60

The difference between the minimum and maximum recovery rates across diameter classes was highest in LT15, moderate in LT20 and the least in LT40 as seen in Table 4.11 above.

Table 4.12

Effect of log diameter on recovery rates

Diameter Class (cm)	Minimum recovery rate (%)		% recovery increase	
	C. lusitanica	*P. patula*	*C. lusitanica*	*P. patula*
10-14	40	38	0.00	0.00
15-19	31	58	0.77	1.52
20-24	33	44	1.06	0.75
25-29	42	38	1.27	0.86
30-34	25	39	0.59	1.02
35-39	36	34	1.44	0.87
40-44	46	37	1.27	1.08
45-49	29	34	0.63	0.91
50-54	44	35	1.51	1.02
55-59	60	37	1.36	1.05
Average	43	39	1.10	1.01

Lumber recovery from the three Wood-mizers LT15, LT20 and LT40 machines varied with the diameter classes of the Logs and species. For the smaller diameter classes, the recovery percentage was characteristically low due to the high surface to volume ratio of the logs. Normally, large diameter logs yield more lumber per volume of input than small diameter logs, (Steele, 1984). Logs with lesser diameters gave high wastages and hence lesser recovery rates whereas logs with large diameters had high recovery rates.

The general trend is that an increase in the diameter of logs and hence volume across species, lead to an increase in lumber recover rate. The conversion efficiency for *C. lusitanica* is however generally higher than that of *P. patula* (table 4.11) due to differences in mechanical and chemical properties between the two species (Yang *et al.*, 2020). As it can be seen in Table

4.12, an increase in 5cm in log diameter led to a corresponding percentage increase of 1.10 in recovery rate for *C. lusitanica* and 1.01 for *P. patula*.

Table 4.13 below shows that an increase in the lumber recovery rates leads to a corresponding increase in lumber conversion efficiency. This is why Wood-mizer LT20 has moderate conversion efficiency and 52% and 37% recovery rates; both higher when compared with Wood-mizer LT15.

Table 4.13

Conversion Efficiencies and Recovery Percentages of varying log volumes

Machine Type	Wood Species	Log Volume (m^3)	Lumber Volume (m^3)	Conversion Efficiency	Recovery (%)
Wood-mizer LT15	*C. lusitanica*	7.84	3.60		46
	P. patula	10.40	3.86	Low	37
Wood-mizer LT20	*C. lusitanica*	8.37	4.33		52
	P. patula	9.77	3.60	Moderate	37
Wood-mizer LT40	*C. lusitanica*	9.77	5.81		59
	P. patula	9.20	5.87	High	64

4.4.6 Volume of residues and lumber from Wood-mizers LT15, LT20 and LT40

A comparative study was carried out to evaluate the volume and type of residues (sawdust and offcuts) generated during the sawing of *P.patula* and *C. lusitanica* logs using Wood-mizers LT15, LT20 and LT40 as presented in figure 4.3.

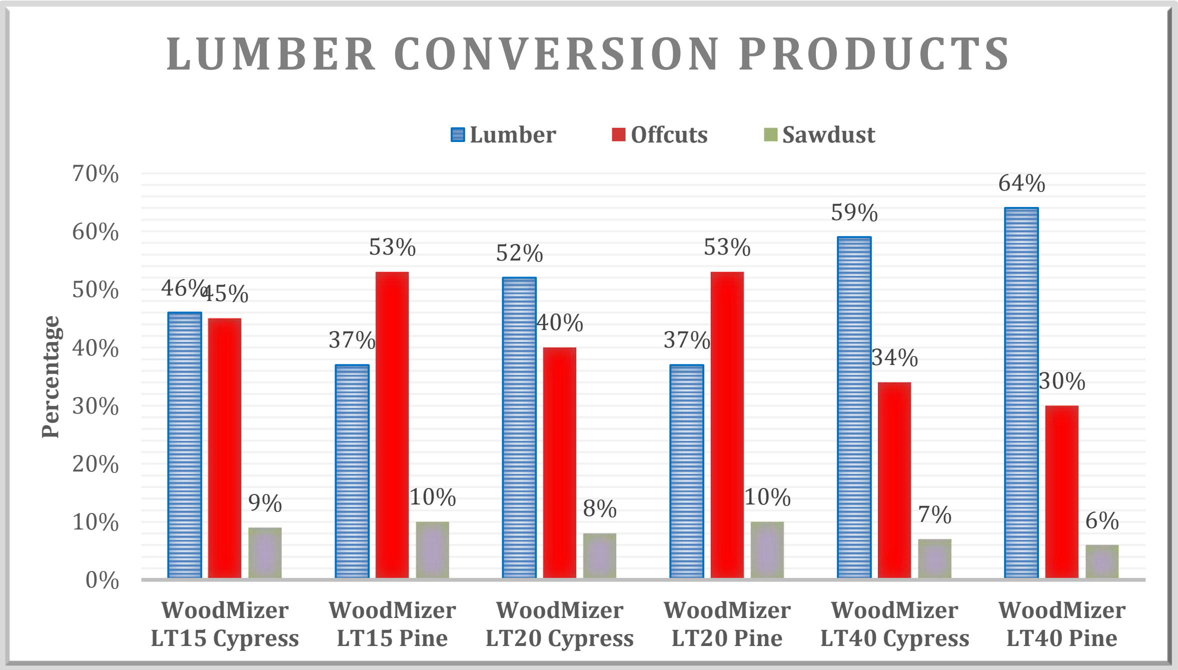

Figure 4.3: Lumber, Sawdust and Off-cuts Generated by the selected Sawmills, 2019

When sawing logs using Wood-mizer LT15 machine, *P. patula* produced the most residues (at 65% of the log volume) compared to *C. lusitanica* (at 54% of the log volume). The same trend was observed when using Wood-mizer LT20. This was attributed manual log handling when using the machines. It is also due to the prohibitive chemical compounds such as resins in *P.patula* logs that offer resistance to the streamlined movement of saw blades through the logs hence interfering with ease of log control during Sawmilling. Wood-mizer LT40 produced the least residues of all the Wood-mizer machines at 41% of *C. lusitanica* and 36% of *P. patula* logs. When converting *P. patula* logs with both Wood-mizers LT15 and LT20, the volume of offcuts was more than the volume of lumber (Figure 4.3)

Table 4.14

Type and Amount of Lumber conversion products in selected Sawmills

Wood-mizer Machine	Lumber Species	Log Volume (m^3)	Lumber volume(m^3)	Off cuts volume(m^3)	Sawdust Volume(m^3)
LT15	*C. lusitanica*	7.84	3.60	3.56	0.68
LT15	*P. patula*	10.40	3.86	5.50	1.04
LT20	*C. lusitanica*	8.37	4.33	3.40	0.64
LT20	*P. patula*	9.77	3.60	5.19	0.98
LT40	*C. lusitanica*	9.77	5.81	2.50	1.46
LT40	*P. patula*	9.20	5.87	2.82	0.51

4.5 Lumber Production Capacity of Wood-mizer Machines

Table 4.15 reports lumber production capacities of LT15, LT20 and LT40 Wood-mizer machines.

Table 4.15

Lumber Production Capacities of Wood-mizers LT15, LT20 and LT40

Wood-mizer	Log Species	Log Volume (m^3)	Lumber Volume(m^3)	Time (Hrs)	Log (m^3) /hr	Lumber (m^3) /hr	Log (m^3) /day	Lumbe r (m^3) /day
LT15	*C. lusitaniaca*	7.84	3.6	3.27	2.4	1.1	19.18	8.8
	P. patula	10.4	3.86	3.13	3.32	1.23	26.57	9.87
LT20	*C. lusitaniaca*	8.37	4.33	3.08	2.72	1.4	21.75	11.23
	P. patula	9.77	3.6	3.02	3.24	1.19	25.88	9.55
LT40	*C. lusitaniaca*	9.77	5.81	2.93	3.33	1.98	26.68	15.9
	P. patula	9.2	5.87	2.9	3.17	2.02	25.37	16.2

Wood-mizer LT40 recorded the highest estimate of daily production capacity for both *C. lusitanica* and *P. patula* (15.9 m^3/day and 16.2 m^3/day) respectively. This was followed by Wood-mizer LT20 at 11.2 m^3/ day and 9.6 m^3/day for *C. lusitanica* and *P. patula* respectively. The daily production capacity for Wood-mizer LT15 was 8.8 m^3/ day and 9.9 m^3/ day for *C. lusitanica* and *P. patula* respectively. This data meant that Wood-mizer LT40 was the most productive of the three Wood-mizers with a production capacity of 1.8 times that of LT15 for

C. lusitanica and 1.6 times when processing *P. patula.* A study on the Sawmill production capacity in selected Sawmills in Alaska, United States of America found that Western Gold Cedar products Sawmill, while operating at 12% of the installed capacity produced 1.9 m^3 of lumber in a day (USSDA Forest Service, 2016). At full capacity, this Sawmill would produce 15.83 m^3 which is comparable with the Wood-mizer LT40 production capacity in this study.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents a summary of research findings, conclusions, recommendations and suggestions for further research.

5.2 Summary

5.2.1 Status of sawmills in Kericho County

Although there are cases of unregistered Sawmills in the County, the study identified a total of 54 registered and prequalified Sawmills. Out of these Sawmills, four of them were large scale, 12 were medium scale and the rest (38) were small scale. Most Sawmills are located around Kericho (30%) and Londiani towns (22%). The main factors considered in siting Sawmills in Kericho County are: the closeness to raw materials, the availability of market demand, nearness to transport infrastructure, the availability of labour and the policies that were in play during the establishment year. Locations such as Tendeno and Chesinende despite having raw materials, they had little demand since Sawmill products required additional transport cost to the market. It is difficult to find Sawmill experts in locations that are far from settlement towns. Most Sawmills in Kericho have been in operation for more than a decade. Registration of new Sawmills is regulated by the Kenya Forest Service. Most Sawmills in Kericho fall within the small scale category. The relatively newest Sawmills in the County were officially registered in 2015 after being vetted by Kenya Forest Service and allowed to register with the Government. All Sawmills in the large scale category have been in operation for more than a decade. Sawmill equipment includes tools and machines to transport, position, cut, and otherwise aid in converting logs into lumber or other processed wood. Most Sawmills had only one machine that was primarily used for log conversion into lumber. While modern Wood-mizer mills are mostly automated, the fundamental sawmill process has changed little over the past ten years. In Kericho County, there still exists horizontal band saws, Circular saws and chain saws despite the invention of the Wood-mizer band saw machines. Most Sawmills operated continuously for 8 hours per day though a few operations below or above 8 hours in day. In this study, the daily production capacity was based on 8 hours to compare the Wood-mizer machine types. Most lumber conversion machines were found to be Wood-mizer LT15. This is because Wood-mizers have a thin kerf narrow bandsaw range that is known for its accuracy and lumber recovery abilities for more profits.

5.2.2 Lumber conversion efficiency of Wood-mizer Machines

The LT15 and LT20 are entry-level mills that are capable of producing good results for sawyers who like converting lumber while minimizing their investment. They are also characterized by heavy duty ball bearing rollers that ensure smooth head travel on bed rails. They also require minimal lifting of the log and allows cuts within 25mm of the bed and both machines are stationery and are characterized by manual log handling. This explains why their lumber conversion efficiency is low compared to LT40. However, with more standard horsepower than the LT15 and the ability to saw unlimited log lengths, the LT20 is better suited to handle longer logs. There was more preference in Wood-mizer LT40. This is because Wood-mizer LT40 has a stationery command center as well as a hydraulic system of log handling which saves on time and energy when operating it. In addition Wood-mizer LT40 has an automatic log turning system that greatly enables the operator get the best log orientation for maximum lumber output.

5.2.3 Lumber recovery rate of Wood-mizers

Since Wood-mizer machines are portable, by taking the Sawmill to the logs, the environmental impact of lumber production is reduced. Wood-mizer’s success in building an affordable and mobile sawmill was solely due to one factor – they used a thin-kerf band saw blade to cut logs. A thin-kerf blade with 1.5 mm thickness and kerf of 2 mm removes a very small amount of wood with each cut compared with circular blades with thicknesses of 6 mm or large bandsaw blades with 3 to 4 mm thicknesses. So with Wood-mizer blades, Sawmillers were able to get more lumber and less sawdust waste from every log. Depending on log size which had an impact on log recovery, total timber recovery was highest in LT40, followed by LT20 and finally LT15. Thin-kerf technology saves on raw materials by producing the same level of final wood products with less raw timber. LT40 gave the highest recovery rates (74% and 87%) for different top diameter classes of *C. lusitanica* and *P. patula* respectively. *P. patula* produced the most residues (61%) compared to *C. lusitanica* (57%) per log volume from both LT15 and LT20 but less from LT40 (47% for *C. lusitanica* and 40% for *P. patula* logs.

5.2.4 Lumber production capacity of Wood-mizer machines

Understanding production capacity helps to optimize production and use resources more wisely. If capacity is much higher than the demand for products, then employees may not have much work to do and equipment may sit out of use. High production capacities are critical in ensuring economy of labour, economies of bulk buying of raw materials, economies of overhead costs and economies of rent of the Sawmill. Wood-mizer LT40 was the most productive of the three Wood-mizer machines with a production capacity 1.8 times that of LT15 for *C. lusitanica* and 1.6 times when processing *P. patula.* The general trend is that the more the machine sophistication the more the lumber production capacity.

5.3 Conclusions

A total of 54 registered and prequalified Sawmills (four large scale, 12 medium scale and 38 small scale) were operating in the County of which 30% were located around Kericho town and 22% in Londiani. Technology has changed sawmill operations significantly in recent years, emphasizing increasing profits through waste minimization and increased energy efficiency as well as improving operator safety. Thin-kerf technology saves on raw materials by producing the same level of final wood products with less raw materials. With a mobile sawmill, logs are converted into valuable lumber and marketable wood products with the same or better quality than available previously. Most Sawmills have adopted Wood-mizer machines as their primary lumber conversion machine though there are those that still characterized by under-capitalization and rely on the traditional circular saws for conversion.

Conversion efficiency of Wood-mizer LT15 was classified as low, in comparison with LT20 which was classified as moderate and LT40 as high. This is mostly due to their inbuilt characteristics.

Recovery of *C. lusitanica* gave average empirical values of 43%, 49% and 53% in comparison with 39%, 34% and 60% for *P. patula* using Wood-mizer LT15, LT20 and LT40 respectively.

Wood-mizer LT40 recorded the highest daily production capacity for both *C. lusitanica* (15.9 m^3/day) and *P. patula* (16.2 m^3/day). This was followed by Wood-mizer LT20 at 11.2 m^3/ day and 9.6 m^3/day for *C. lusitanica* and *P. patula* respectively. Wood-mizer LT15 had the least production capacities of 8.8 m^3/ day for *C. lusitanica* and 9.9 m^3/ day for *P. patula*.

5.4 Recommendations

In an effort to increase the utility efficiency which in turn leads to relative sustainable conservation of forests, the following recommendations are made;

1. Sawmilling industry in Kenya should be encouraged to adopt Wood-mizer Sawmilling machinery/ technologies to enhance wood conversion efficiencies and minimize wastage.

2. Awareness creation among tree growers should be enhanced about sustainable lumber efficient technologies

3. Kenya Forest Service and Sawmillers to organize a training program for Sawmilling employees about efficient technologies and practices to enhance employee performance, boost employee productivity, reduce employee turnover, and reduce Sawmilling wastes.

4. When deciding on the machine to buy from Wood-mizers LT15, LT20 and LT40, bias of LT40 machine should be applied. This is because this machine gives an advantage on Lumber conversion efficiency, recovery rate and production capacities over LT15 and LT20.

5.5 Suggestions for Further Research

Whereas the study was thorough on the objectives that it was initially set out to achieve, there were a number of issues and topics that came up that require further study and understanding. Some of these issues fell out of the scope of this study. These areas are suggested as follows:

1. What is the effect of log taper on lumber recovery rates in Kericho County?
2. What implications does increase log conversion efficiencies have on forest resources management?
3. To what extent does increase in production capacity of Sawmills in a region such as Kericho through the use of efficient processing machines affect the sustainable management and use of tree resources?
4. What are other factors impacting on lumber recovery percentage in Sawmilling?

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APPENDICES

Appendix 1: Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

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Date of Issue: **12/September/2019**

RESEARCH LICENSE

This is to Certify that Mr.. BONIFACE MULWA of University of Kabianga, has been licensed to conduct research in Kericho on the topic: DETERMINING PRODUCTION CAPACITY AND RECOVERY RATES OF Cupressus lusitanica AND Pinus patula LUMBER FROM SELECTED WOODMIZER MACHINES IN KERICHO COUNTY, KENYA for the period ending : 12/September/2020.

License No: **NACOSTI/P/19/1229**

830766

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

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Appendix 2: Kericho Forest Plantations Management data

County	Station	Sub-compartment	Species	YOP	Area (Ha)
Kericho	Malagat	MALAGET 4E	A.Mel	2000	8.1
Kericho	Sorget	SORGET 4F	A.Mel	1997	11.2
Kericho	Kerisoi	SITOTON 7A	Acacia.Species	1985	16.2
Kericho	Kericho	CHEBOSWA 1D	Araucaria	1957	0.6
Kericho	Kericho	KIBULGIN 1D	Araucaria	1980	0.6
Kericho	Sorget	SORGET 12A	C.Lus/A. Mel	1999	34.6
Kericho	Kerisoi	KERISOI 2J	Cedar	1929	9.1
Kericho	Kerisoi	KERISOI 2K	Cedar	1931	59.5
Kericho	Kerisoi	KERISOI 4A	Cedar	1934	43
Kericho	Sorget	MOLOLO 14E	Cedar	1979	20
Kericho	Sorget	MOLOLO 3A	Cedar	1931	5.4
Kericho	Londiani	KEDOWA 1C	Cedar	1941	4.4
Kericho	Londiani	KEDOWA 1F	Cedar	1941	6.3
Kericho	Londiani	KEDOWA 1H	Cedar	1936	4.3
Kericho	Londiani	KEDOWA 1I	Cedar	1925	18.4
Kericho	Londiani	KEDOWA 1L	Cedar	1941	7.1
Kericho	Londiani	KEDOWA 1M	Cedar	1941	1.2
Kericho	Londiani	KEDOWA 1N	Cedar	1925	5.8
Kericho	Londiani	KEDOWA 2A	Cedar	1922	18.93
Kericho	Londiani	KEDOWA 2C	Cedar	1922	4.54
Kericho	Londiani	KEDOWA 2E	Cedar	1922	1
Kericho	Londiani	KEDOWA 2H	Cedar	1931	22.5

Kericho	Londiani	KEDOWA 2I	Cedar	1941	9.7
Kericho	Londiani	KEDOWA 2K	Cedar	1933	10.53
Kericho	Londiani	KEDOWA 2M	Cedar	1943	10.2
Kericho	Londiani	KEDOWA 3A	Cedar	1936	2.2
Kericho	Londiani	KEDOWA 3E	Cedar	1945	26.8
Kericho	Londiani	MT BLACKETT 4E	Cedar	1943	7.1
Kericho	Londiani	MT BLACKETT 5A	Cedar	1953	10
Kericho	Londiani	MT BLACKETT 6A	Cedar	1923	38.1
Kericho	Londiani	MT BLACKETT 7E	Cedar	1943	3
Kericho	Londiani	MT BLACKETT 8A	Cedar	1924	28.2
Kericho	Londiani	MT BLACKETT 8E	Cedar	1929	2.2
Kericho	Londiani	MT BLACKETT 8I	Cedar	1946	2.7
Kericho	Londiani	MT BLACKETT 10B	Cedar	1936	5.6
Kericho	Londiani	MT BLACKETT 11B	Cedar	1935	37.2
Kericho	Londiani	MT BLACKETT 11D	Cedar	1935	18.8
Kericho	Londiani	MT BLACKETT 11G	Cedar	1935	12.1
Kericho	Londiani	MT BLACKETT 11I	Cedar	1941	17.3
Kericho	Londiani	MT BLACKETT 12A	Cedar	1939	50.4
Kericho	Londiani	MT BLACKETT 12B	Cedar	1940	30.5
Kericho	Londiani	MT BLACKETT 12C	Cedar	1941	9.7
Kericho	Makutano	KAMPI KONGONI 5A	Cedar	1935	16.1
Kericho	Makutano	KAMPI KONGONI 5B	Cedar	1930	9.8
Kericho	Makutano	KAMPI KONGONI 7H	Cedar	1998	1.9
Kericho	Londiani	KEDOWA 2L	Mex.Ash	1943	3.6

Kericho	Londiani	KEDOWA 3E	Mex.Ash	1945	1
Kericho	Londiani	KEDOWA 3F	Mex.Ash	1945	8.2
Kericho	Londiani	KEDOWA 3I	Mex.Ash	1999	5.8
Kericho	Londiani	KEDOWA 3N	Mex.Ash	1951	2.3
Kericho	Makutano	KAMPI KONGONI 2E	Mex.Ash	1953	3.3
Kericho	Makutano	KAMPI KONGONI 3A	Mex.Ash	1946	5.2
Kericho	Makutano	KAMPI KONGONI 4C	Mex.Ash	1945	4.3
Kericho	Londiani	MT BLACKETT 4N	Mixed Indige	2014	19.4
Kericho	Londiani	MT BLACKETT 7F	Mixed Indige	—	5.1
Kericho	Londiani	MT BLACKETT 9B	Mixed Indige	2014	4.6
Kericho	Londiani	MT BLACKETT 10A	Mixed Indige	2014	12.5
Kericho	Londiani	KEDOWA 1A	Mixed Indige Spp	2008	14
Kericho	Sorget	MOLOLO 2A	Mixed.Spp	1998	6.2
Kericho	Londiani	MT BLACKETT 9H	Mixed.Spp	—	6.3
Kericho	Londiani	KEDOWA 1E	N.Reg. Mixed Spp	_	10.3
Kericho	Londiani	KEDOWA 1K	N.Regenaration	—	14.5
Kericho	Londiani	KEDOWA 2D	N.Regeneration	_	23.9
Kericho	Londiani	MT BLACKETT 7B	N.Regeneration	_	8
Kericho	Londiani	MT BLACKETT 11B	Podo	1935	2
Kericho	Londiani	MT BLACKETT 7E	Podo/Cedar	1943	3.4
Total					**826.8**

Appendix 3: Prequalified Sawmills in Kericho County

No	Name of Sawmill	Sawmill Category	Sawmill Location
1	Frankways Mills Ltd	Large	Kericho
2	Lel Timber Sawmills	Large	Kericho
3	Rosoga Investment Ltd	Large	Londiani
4	Mathai Timber Sawmills	Large	Malagat
5	Emolo Timber Yard Ltd	Medium	Kerisoi
6	Mbugua Gatembu Sawmill	Medium	Kerisoi
7	Finley Sawmill	Medium	Kericho
8	Kenza Sawmill Ltd	Medium	Kerisoi
9	Igure Investment Sawmill	Medium	Makutano
10	Dundum Sawmill	Medium	Makutano
11	Sarididi Investments	Medium	Kericho
12	Kipleso Sawmill	Medium	Londiani
13	Timsos Ltd	Medium	Kericho
14	Rutoh Sawmill	Medium	Kericho
15	Reenis Enterprises Ltd	Medium	Londiani
16	Bethwel Muiruri Njoroge Sawmill	Medium	Kerisoi
17	Kiptarugu Sawmill	Small	Malagat

No	Name of Sawmill	Sawmill Category	Sawmill Location
18	Gekiwa Sawmills	Small	Londiani
19	Denix Enterprises Ltd	Small	Chesinende
20	Pearl Construction Ltd	Small	Kericho
21	Wahogo Sawmill	Small	Malagat
23	Borsam Timber Products	Small	Kericho
24	Ranjom Enterprises	Small	Kericho
25	Lochen Trucks Ltd	Small	Kericho
26	Equator Willie Sawmill	Small	Makutano
27	Framawa Sawmills	Small	Tendeno
28	Reche Agencies	Small	Londiani
29	Super Molo Timber Yard	Small	Kerisoi
30	Dormer Sawmill	Small	Kericho
31	Mau Summit Sawmill	Small	Kericho
32	Mandi General Constructor	Small	Tendeno
33	Robeto General Sawmiller Ltd	Small	Londiani
34	Borsim Sawmill	Small	Kericho
35	Burgeison Company Ltd	Small	Londiani
36	Hekima Sawmill	Small	Kerisoi

No	Name of Sawmill	Sawmill Category	Sawmill Location
37	Francis Maritim Sawmills	Small	Londiani
38	Leniko Sawmill Enterprises	Small	Kericho
39	Londiani Farmers	Small	Londiani
40	Makutano Investment Ltd	Small	Kericho
41	Majani Rono Sawmill	Small	Londiani
42	Charles Omechi Kinanga	Small	Kerisoi
43	Kap Mutial Mills Ltd	Small	Malagat
44	Peter Nzioka Sawmill	Small	Malagat
45	Dawamu Traders Ltd	Small	Kericho
46	Kurguy Enterprises Ltd	Small	Londiani
47	Joyce Rotich Sawmill	Small	Londiani
48	John Chui Sawmills	Small	Malagat
49	Adama Investment	Small	Makutano
50	Borers Enterprises	Small	
51	Tendeno Gaa Youth Group	Small	
52	Bimawood Sawmill	Small	
53	Woodlands Company (K) Ltd	Small	
54	Reje Investment	Mall	

Appendix 4: Study Questionnaire

Introduction

I am a post graduate student at the University of Kabianga pursuing Master of Science in Forestry. You have been selected to participate in this study and kindly requested to respond to survey questions below. The purpose of this questionnaire is to help collect responses to be used only for academic research; your responses will be treated with utmost confidentiality. Do not write your name or telephone number.

This is a questionnaire intended to determine how efficiently Sawmills in Kericho County operate.

Part A. Sawmill Status

A1. What is the name of your Sawmill? ____

A2. When was the Sawmill started?

This year ☐ 1 year ago☐ 2 years ago☐ 3 years ago☐ Over 3 years ago☐

A3. How many machines does the Sawmill have? ________________________________

A4. How many workers has the Sawmill employed? _____________________________

A5. How many hours per day is the Sawmill open? _____________________________

Part B. Machines

B1. Which machine(s) do you use primarily for log conversion? ___________________

B1. Do you have any of the following machines? (Tick the ones available).

Wood-mizer LT15 ☐ Wood-mizer LT20 ☐ Wood-mizer LT40 ☐

B2. Please rate the following machines in terms of their lumber conversion efficiency in terms of ease of operation. (Tick where necessary).

Machine	**Low**	**Moderate**	**High**	**Not aware**
Wood-mizer LT15				
Wood-mizer LT20				
Wood-mizer LT40				

B3. Is there any recovery performance difference between Wood-mizer LT15, Wood-mizer LT20 and Wood-mizer LT140 in terms of time?

____

B4. Can you rate the level of log wastage using the following machines?

(Tick where necessary).

Machine	**Very Low**	**Low**	**High**	**Very High**
Wood-mizer LT15				
Wood-mizer LT20				
Wood-mizer LT40				

B5. What is the log recovery rate of the following machines?

Machine	**Recovery rate**
Wood-mizer LT15	
Wood-mizer LT20	
Wood-mizer LT40	

<u>Part C. Sawmills</u>

C1. What is your logs' species composition? __________________

C2. Where do you source your logs from? (Tick where applicable)