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FACULTY OF RENEWABLE NATURAL RESOURCES

DEPARTMENT OF WOOD SCIENCE AND TECHNOLOGY

WOOD RESIDUE GENERATION AND UTILIZATION: THE TECHNICAL, ECONOMIC AND ENVIRONMENTAL MIX FOR SOME SELECTED SAWMILLS IN BRONG AHAFO AND ASHANTI REGIONS, GHANA.

BY

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MSC. WOOD TECHNOLOGY AND INDUSTRIAL MANAGEMENT

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BY

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A Thesis submitted to the Department of Wood Science and Technology,

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DECLARATION

I hereby declare that the studies described in the thesis are my own original work except references to other people‟s work which have been duly cited. To the best of my knowledge none of the work contained herein has been previously presented for the award of any Degree in any University.

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DEDICATION

This Thesis Work is dedicated to my Late Father, Mr. Samuel Augustus Cudjoe Fordjour for his encouragement. Daddy, this has always been your dream.

ABSTRACT

The recovery rates of sawmills in Ghana are low (about 28-64%), leading to pressure on the limited available resources. Consequently, there is the need for studies into wood residue generation and utilization to address the situation. This study was carried out in four prominent sawmills in the Ashanti and Brong Ahafo regions of Ghana with four frequently processed timber species at the sites. These included *Cylicodiscus gabunensis* (denya), *Entandrophragma angolense* (edinam), *Pterygota macrocarpa* (koto) and *Triplochiton scleroxylon* (wawa). The first study involved a survey to determine the availability, types, quantity, production rates, composition and utilisation of wood residues. Wood residues identified in the production processes were sawdust (14.65%); slabs (27.15%); edgings (40.84%); and trimmings (17.36%). The average percentage lumber recovery at the four sawmills was 38.08% with residue forming 61.92% of the total input volume. The edger produced volume of coarse residues that was significantly greater ($P \geq 0.05$) than that of the other machine levels, however, the volume of sawdust residue was statistically significantly lower for machine level, edger and trimmer, compared to the bandmill. The second study determined the uses of wood residues and the economics of wood residue utilization at the study sawmills. The study revealed that residues generated had no economic benefits at the study sawmills. The lesser the quantities of residues generated, the better the sawmill profitability, hence a better sustainable forest management. The cost of production in the timber industries were in the order raw material > electricity > transportation > labour > maintenance > general overhead > sawdust carting; so efficient utilization of raw material is very important. The third study was conducted using fieldwork, laboratory work and personal observations to determine the

decomposition trends of wood residues. Generally sawdust residues decomposed at a very low rate (only about 35% decomposition of test samples during three months). There was no significant differences ($P \geq 0.05$) between the rate of decomposition of the buried sawdust and the surface applied sawdust. The forth study determined the constraints in handling sawdust for power generation and its effect on the environment and human health. It was revealed that 9.07% of input volume generates sawdust, however; about 60% of the sawdust was not utilized but dumped and burnt openly, making the environment aesthetically unclean and causing health hazards to surrounding communities. It was recommended that wood residue producers should form partnership to facilitate its transportation, storage and marketing. They could also consider its value-added manufacturing processes into finger joints, crafts and toys, floorings and garden fencing. Fines such as sawdust could be used to manufacture briquette for household use or biochar for soil amendment to enhance nurseries, plantations and other agricultural interests for sustainable forest management purposes. This study consistently identified minimizing wood waste as a major point of departure for reducing the environmental impact of timber sector of Ghana. There is the need to train workers to upgrade their skills to meet the new technological challenges that might arise in the area of production. The findings could be used in the future planning towards a more cost effective management of wood flow of the selected species and their
utilization.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAC Annual Allowable Cut
ABC Activity-Based Costing
ABTS Asuo Bomosadu Timber and Sawmill
AFPL Ayum Forest Products Limited
BC British Columbia
BLLC Bibiani Logs and Lumber Limited
BOD Biological Oxygen Demand
BoG Bank of Ghana
BTUs British Thermal Units
CFDC Community Futures Development Corporation
CBIE Canadian Bureau for International Education
CHP Combined Heat and Power
CSIR Council for Scientific and Industrial Research
CTSL Cargill Technical Services Limited
DFAIT Department of Foreign Affairs and International Trade - Canada
EEA European Environments Agency
EPA Environmental Protection Agency
FAC Food and Agriculture Council
FAO Food and Agriculture Organization
FFRT Faculty of Forest Resources Technology
FFTC Food and Fertilizer Technology Centre
FORIG Forest Research Institute of Ghana
FSC Forest Stewardship Council
FWG Forest Watch Ghana
HSD Honest Significant Difference
IEA International Energy Agency
IIED International Institute for Environment and Development
ITTO International Tropical Timber Organization
JUCA Jimma University College of Agriculture (Ethiopia)
LLL Logs and Lumber Limited MBDt
Millions of Bone Dry Tonnes.
MC Moisture Content
MELP Ministry of Environment, Lands & Parks
MLF Ministry of Lands and Forestry
NISER National Institute of Science Education and Research
OSHA Occupational Safety and Health Administration
PVA Poly Vinyl Acetate
Q&A Questions and Answers
RMRDC Raw Material Research Development Council
SWANA Solid Waste Association of North America
TEDB Timber Export Development Board
TIDD Timber Industry Development Division
TRADA Timber Research and Development Association

TSS	Total Suspended Solids
TUC	Timber Utilisation Contract
UNDP	United Nations Development Project
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNIDO	United Nations Industrial Development Organisation USDA

United State Department of Agriculture

CHAPTER ONE

1.0 GENERAL INTRODUCTION

The efficient use of forest resources is vital to forest sustainability. Ghana has come a long way in her effort to develop her natural forests for timber production and consumption. Consequently, in addition to supplying timber for domestic consumption and for export purposes, there must be reviews that are geared towards ensuring increased mutual benefit for Ghana and posterity. Logging, wood processing and storage generate a considerable amount of waste. These bring the natural forest which is the main source of raw material for the wood industry under threat. Using wood carefully with minimum waste is also a vital component of sustainable timber use, but this has been less of a focus to date (Magin, 2001).

Wood residues like sawdust, trimmings and edgings are typically viewed as a burdensome disposal problem (FAO, 1990), however, the materials have potential to become usable resource. Ghana is in a position to take up this advantage since the timber industries have average yield of about 28-64% (Gyimah and Adu-Gyamfi, 2009), with majority of the wood resources going to waste. Wood residue could be decomposed in the soil to improve soil structure and fertility (Mensah, 1998) for food crops to enhance food security. Thus, there will be no need to clear more hectares of land for the same quantity of food, hence forest maintained. Also, the use of natural wood residue or biochar could improve soil structure (Lehmann and Joseph, 2009), hence improvement upon the yield of the plantation crops or wood lots.

1.1 Justification

The forest products sector in Ghana is a major contributor to the country‟s employment and economic growth (Bonsi *et al.*, 2011). The forest is not only important for material goods but also serves as valuable ecological and cultural resources. The forestry sector has over the years contributed immensely to the socio-economic development in the country. The wood industry in Ghana‟s economy ranked fourth and trailed only gold, tourism and cocoa in export earnings (Ghana Forestry Commission (GFC), 2009). In 2010, exports totaled US$ 181 million in value with a corresponding volume of 426,220m^3 (GFC, 2011). Nonetheless, the wood industry is increasingly being constrained by acute raw material shortages due to excessive harvest of timber and other anthropogenic activities (Bank of Ghana, 2004; GFC, 2006). The bulk of Ghana‟s timber is located in the country‟s high forest zone. However, most of the original forest in this area has been cleared and the remaining closed canopy forest is now found in forest reserves and a few patches of unreserved forests (Cargill Technical Services Limited, 1993). According to (ITTO, 2005) the country might be losing almost 6 million m^3 of timber per annum.

The state of the forest has therefore resulted in the adaptation of stricter control on timber exploitation, which is undoubtedly expected to affect the timber industries (Ayarkwa, 1998; Oteng-Amoako, 2006). An Annual Allowable Cut (AAC) which is the maximum volume of timber that can be felled each year without reducing the long-term sustainability of the forest resources (Ghana Forestry and Wildlife Policy, 2012) has been set at one million, five hundred thousand cubic meters (1,500,000m^3) for round logs from both forest and off-reserve areas (Kasanga, 2002a; Oteng-Amoako, 2006). Logging is now being done unsustainably because even the 1,500,000m^3 a year estimate, has been exceed by 2,000,000m^3, which means that in 10 years, 35,000,000m^3 are felled instead of the projected 15,000,000m^3 during the same period (Ayarkwa, 1998). Thus, the demand for wood is so alarming that this AAC is woefully inadequate to meet the nation's demand for wood, hence, posing a threat on the long term sustainability of the timber industry.

Dost (1966) also defined wood residue as the remnant of the original raw material after the economic value has been removed. Gyimah and Adu-Gyamfi (2009) reported a lumber yield of about 28-64%. This means, more than half of the raw materials sent to the timber industries come out as waste. With the recent increase in population growth of 2.1% per annum (www.data.worldbank.org/indicator/SP.POP.TOTL), and increase in the construction industries in Ghana, the allocation of the AAC seems insufficient and indicates a gloomy future for raw material supply to the timber industries (Ayarkwa, 1998).

An intervention for salvaging the dwindling rate of Ghana‟s natural forest resources is to reduce the rate of production of wood residue and also make maximum use of the unavoidable wood residue. To take advantage of the market opportunities that exist for wood residues, information is needed on the availability, quantity and production rates, types of wood residues being produced, current markets and disposal practices of wood residues.

1.2 Scope of the study

This study focused only on the wood processing residues from sawmills. Four timber industries were selected from the Ashanti and Brong-Ahafo Regions of Ghana. Four timber species with higher rates of processing were used. Decomposition and water holding capacity tests were run for the sawdust of the selected species.

1.3 Objectives

The main objective of the study was to assess the efficiency of production, utilization, economic values and environmental effects of wood residues.

The general objectives are;

1. To determine the amount of wood residues generated at each machine centre of the production lines of the selected saw mills.
2. To evaluate existing uses of the residues and their economic values.
3. To assess the decomposition trend of the wood residues.
4. To assess some environmental implications of these wood residues.

1.4 Research questions considered

Research questions deduced from the objectives were;

- What percentage of input log volume generated residues at each machine centre?
- What are the various wood residues and their quantities produced in the sawmill?
- What are the existing uses of wood residues and their profitability?
- What is the trend of decomposition of the wood residues?
- How does wood residue affect the environment?

1.5 Limitations of the study

Trees are living organisms with a great variability in structure and properties. The variability exists as inter- and intra-tree variations. The environmental conditions are also one important source of wood anatomical structure variability which influences the physical and mechanical properties (Gryc and Horácek, 2007), but, the samples used did not cover all potential ranges of variability. The ages of the trees collected for this study were unknown because they were from the natural forest. The species were selected based on the records of the timber industries of higher volumes for export (between 110.00m^3 - 130.00m^3 per month). Thus the most frequently used species were selected.

1.6 The structure of the thesis

Chapter One is the introductory chapter which provides the background of the study, problem statement, justification, scope, research objectives and research questions. **Chapter Two** is the literature review, which gives an account of what has been published on the topic by accredited scholars and researchers.

The experimental **Chapters (Three – Six)** provide, an introduction, specific objectives, materials and methods, results, data analysis, discussion and conclusions of each specific study or experiment.

Chapter Seven is the general conclusions and recommendations of the research. This gives a summary of the outcomes and makes relevant recommendations to enhance qualitative and quantitative achievements in future wood processing. It also opens windows for further research. **References** and **Appendices** are presented after Chapter Seven.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Forest Resource Base of Ghana

The total land area of Ghana is about 23.9 million ha with a coastline of 567km. It is divided into two main ecological zones, the high forest zone of the Southern Ghana, covering about 8.2million ha (34%) and the Northern savanna zone covering 15.7milllion ha (66%) (Hall and Swaine, 1981). According to Ghana Gazette (2007), Ghana"s timber comes from the high forest zone where there are 216 Forest Reserves covering about 17,000 square kilometres. Of these, about 12,000 square kilometres are productive, 4,500 square kilometres are primarily protective and 500 square kilometres are for research. Outside the high forest zone is the Savannah region of 8,000 square kilometres of reserve which have protective and community support roles.

The right to harvest naturally occurring timber is enshrined in section 1 and 4 of the Timber Resources Management Act (1998, Act 547): except in the case of land with private forest plantations or lands with timber grown or owned by an individual or group, no person shall harvest timber unless that person holds timber rights in the form of a Timber Utilisation Contract (TUC) (ClientEarth, 2013).

International Tropical Timber Organization (ITTO) reported on the annual review assessment of the world timber situation indicated that the timber industry in Ghana is facing a raw material supply shortage at an unprecedented scale (ITTO, 2002). This has resulted in a collapse of some timber firms with the added threat of unemployment (Bank of Ghana, 2004). This problem is partly due to inefficient wood processing techniques leading to over exploitation of the forest (FAO, 1990).

2.2 The State of the Forest in Ghana

The forestry sector is one of the main pivots on which a nation's welfare is built (Magin, 2001). The forest is not only important for material goods but also as a valuable ecological and cultural resource. Forests perform a wide range of functions, including watershed protection, soil conservation, and provision of timber and non-timber forest products, climate stabilization and carbon storage. They are home to human communities as well as providing the habitat for a huge proportion of the world"s plant and animal species (Magin, 2001).

According to Forest Watch Ghana (FWG) (2008), between 1909 and 1990, Ghana has lost 80% of its forest cover with 65,000 hectares vanishing annually. Between the year 2000 and 2005, Ghana lost an average of 115,400 hectares of forest per year (Dogbevi, 2008). Excessive logging waste, low processing recovery and a lack of pragmatic policies are among the causes of the depletion of the forest resource base (Bank of Ghana, 2004). Natural forest in developing countries decreased by 13.7 million hectares a year between 1990 and 1995 (FAO, 1999). In addition to this deforestation, degradation – a decrease in the ecological quality of forest – is occurring on an equally large scale. While the causes of forest loss and degradation are numerous, logging for the timber industry is undoubtedly a significant factor in many areas (Dudley *et al.*, 1995). Using wood carefully with minimum residue is a vital component of sustainable timber use, but one that has been less of focus to date.

2.3 Ghana’s Timber and Wood Processing Industries

The forest sector in Ghana is dominated by the timber industries and ranked fourth to gold, tourism and cocoa in Ghana‟s economy (Ghana Forestry Commission (GFC), 2009). However, Ghana has about 80% of its forest cover destroyed in less than 100 years (FWG, 2008). In terms of economic contribution, forestry and logging accounted for 3.7 percent of GDP in 2009 and contributed US$240.9 million (representing 7.6%) to total export value. It is estimated that about 120,000 people are formally employed by the forest and wildlife sector, and it serves as a source of livelihood for about 2 million people. There are 84 sawmills and 12 companies with plywood capacity in the formal sector, directly employing about 120,000 people (Country Environmental Analysis, 2007). In the informal sector, however, a wide mix of actors and rural households depend on forest resources for their livelihoods, ranging from micro/small scale carpentry, hunting, illegal chain-saw operations, and wood fuel collection to the gathering and commercialisation of diverse non-timber forest products (NTFPs). About 11 million people live in forest areas of which about 67 percent of their livelihoods are supported by forest activities (Ghana Forest and Wildlife Policy, 2012).

The fast diminishing quantity of merchantable timber has made the idea of efficient timber use an attractive approach of helping to reduce waste that has hitherto characterized wood processing in Ghana (RMRDC, 1991).

2.3.1 Sawmilling

Sawing is defined as a process of converting logs into lumber with sawdust, slabs and off-cuts as by-products. Sawing technology is the mechanization of man‟s earliest activities towards human settlement and development by cutting wood into sizes useful for the satisfaction of human demand (Martyr, 1973). Lucas (1995) defined sawmilling as the process of converting round wood from the forests into lumber by using a variety of machines. Sawmilling, which is usually considered as a simple manufacturing process, (i.e. cutting down a tree, sawing, and generating lumber), is in fact a highly technical and sophisticated industry that must be constantly monitored so that businesses can respond to change effectively (Guyana Forestry Commission, 2012). The history of sawmilling dates back to the 18th century with pit-sawing as the earliest form of log conversion while the first power-driven sawmill was installed at the beginning of the 20th century (Akachukwu, 2000).

The purpose and goals of sawmilling operation as expressed by Walli (1988) are:

- to produce sawn timber for construction and joinery purposes,
- to produce standard sizes and qualities of sawn timber,
- to carry on production economically and profitably, and
- to recover maximum grade value whilst getting maximum volume production per hour.

2.3.2 Sawmill Production Machinery

Lumber is manufactured by a collection of machine centers that have specific functions and must work in conjunction with one another to produce lumber. Collectively, these machines make up a manufacturing system known as a sawmill (Rappold, 2006). The three main processes that are involved in the manufacture of hardwood lumber are primary breakdown (e.g. bandmilling), edging, and trimming (Figure 2.1).

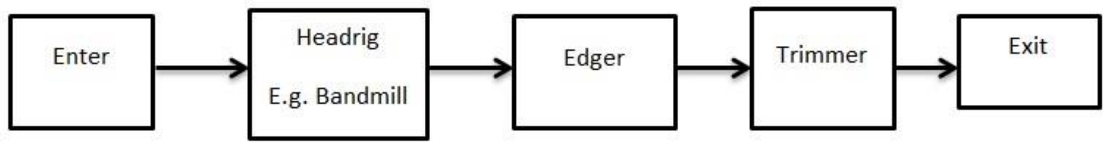


Figure 2.1 The basic material flow pattern in a hypothetical sawmill (Rappold, 2006).

Primary log breakdown is done at the "headrig", edging is done at the "edger", and trimming is done at the "trimmer" (Rappold, 2006). To convert round logs into lumber, it is necessary first to reduce the log to boards or planks. This process is called breakdown. There are three basic types of log breakdown equipment, the circular headsaw, the band headsaw and the gang headsaw. Collectively the headsaw along with a log carriage and a log turner make up what is known as a headrig. Headrig types include circular saws, bandsaws and framesaws (White, 1980).

Band Saws

Band saws are used by large sawmills. They consist of continuous wide steel bands with teeth on one or both edges mounted on two wheels. Band saws have solid teeth as contrasted with the inserted teeth ordinarily found on the circular headsaws. Most band headsaws are single cutting, i.e., they have teeth on only one edge and cuts on the forward stroke (Panshin *et al.*, 1962). Band saws have thinner kerfs, flexible, have higher feed and can accommodate larger logs. They are more expensive to purchase and maintain (Cooper, 1994).

Circular Saws

The circular headsaw consists of a circular saw of large diameter mounted on a mandrel. The log is supported on a carriage that moves on a double track situated approximately parallel to the plane of the saw blade. Most circular headsaws are of the inserted-tooth variety (Panshin *et al.*, 1962). According to Cooper (1994), the circular saws are usually cheaper than the other saws. They require less expensive foundation and are generally cheaper to maintain. However their saw kerf is much wider compared to that of band saws leading to more sawdust production (Alderman, 1998; White, 1980).

Frame / Gang Saws

Gang headsaw differs from the circular and band headsaw in that the cuts made to achieve log breakdown are accomplished simultaneously instead of consecutively. This equipment is made up of two or more straight blades fixed parallel to each other on a frame with teeth on one edge. They are of two types; the vertical and horizontal frame saws. The vertical saw is the most common one with blades set at pre-determined distances on the frame that reciprocate vertically (Panshin *et al.*, 1962). According to Cooper (1994), their saw kerf lies between that of band saw and circular saw.

2.4 Conversion of Timber

Conversion is the process of sawing logs or bolts into square edged pieces of timber suitable for use by carpenters, joiners and cabinet makers. Lumber is the product of sawmill conversion. Lumber is a rectangular length of wood sawn parallel to the tree stem and cut to specific width, thickness, and length (Briggs, 2008). To manufacture lumber, logs are graded and crosscut for specific lumber lengths. Each crosscut log (bolt) is sawn lengthwise at measured intervals to produce boards of a given thickness. These boards are cut lengthwise to square the edges by removing the round outside surface of the log and to produce lumber of standardized widths. Then the ends of the boards are squared to produce lumber of standard lengths (Briggs, 2008), Plate 2.1.

Plate 2.1 The conversion process of log to lumber showing residues produced

Before every conversion process, the dimensions of the bolts are taken to be able to calculate the conversion efficiency. The commonly used formulae for estimating the volume of bolts are those of Huber, Smalian and Newton (Brack and Wood, 1997).

Smalian's formula, requiring measurements at both ends of a log, is the easiest to apply which explains why it has the widest acceptance world-wide for log scaling (Brack and Wood, 1997).

Volume conversion and grade recovery determines the profitability of a mill. The conversion is defined as the ratio of the volume of green sawn timber that can be cut from a given volume of debarked logs or bolts. Usually, the conversion is based on the nominal sizes being cut (100 x 50mm) rather than the actual green dimensions (102 x 52mm) which allows for sawing variations, shrinkage and planing loss, or it is based on the dry dressed sizes (94 x 45mm).

During the early 1900‟s, sawmill timber conversion efficiency was approximately 35 - 40%. Thus, more than half of each trunk was wasted (Walton, 1974). According to UNIDO (1983), lumber recovery is often between 30 – 40% for developing countries in comparison to 50 - 70% in the developed countries, although the quality of logs is usually better. Appiah *et al.* (1987) reported that the sawn timber recovery factor is influenced by log size, mill type, processing method, product size and other factors.

2.4.1 Conversion / Sawing Patterns

Cooper (1994) defines a sawing pattern or cutting as a predetermined pattern for converting logs into lumber. In all sawing processes, the location of opening face (the first longitudinal cutting) is the key to maximum lumber recovery because the position of the first face establishes the position of the remaining faces. All other saw lines will either be parallel or perpendicular to the opening face (Attah, 1996). The cutting pattern adopted for log break down will also affect mill recovery. In practice, the cutting pattern is determined by the available saws, the class of timber, the log quality and size, the market demand and the sawyer (Adams, 2007). Some of the sawing patterns that are used in lumber production are explained as follows.

2.4.1.1 Live Sawing (through and through)

Live sawing is a method of sawing which results in all lines parallel and minimizes sawing time. It is suitable when only boards are being sawn. It is also called through and through or plane sawing. It is the simplest cutting method and most commonly practiced by sawmills cutting small diameter logs. Logs are sawn by a series of parallel cuts and it is normally used for low grade logs (How *et al.*, 2007). Gang saws (frame saws) are used for live sawing. In live sawing there is little waste (as low as 30%), and the logs do not have to be turned and returned for re-cutting, hence the milling costs are lower than for other methods. It is suitable for rapid mass production of boards for standard lines such as light framing material, packing case stock and fencing. The method has difficulties in segregating clear timber when converting knotty or defective logs (Walton, 1974).

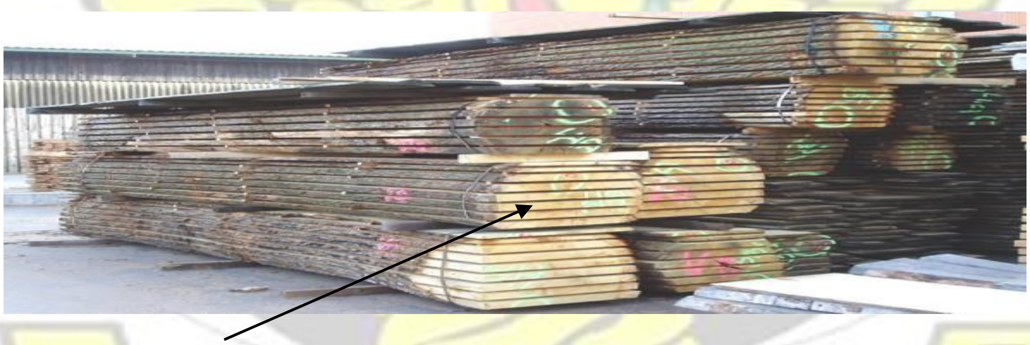


Plate 2.2 Live sawn logs (Source: Timbergreen Forestry, 2011)

2.4.1.2 Sawing Around (Sawing for Grade)

This method saws all faces around the log, turning it as needed to remove each board from the face promising the highest grade. When defects are encountered, the log is turned to its best face. Defects are concentrated in a box heart. Its advantages are that it helps to reduce stress in logs which is incurred during growth, thus helps to reduce warping. However, more time is used in handling logs and it also requires skilled sawyer, thus higher cost of production (How *et al.*, 2007).

The aim of sawing around is – (a) to produce timber pieces which possess various grain characteristics and properties; (b) to separate sapwood from true wood; (c) to obtain a maximum amount of sound timber from faulty or knotty logs (Walton, 1974). It is employed to maximize both the grade and volume recovery. The pattern is best suited for the breakdown of large diameter logs which are able to yield a larger proportion of higher grade of boards than smaller logs (Cooper, 1994).

2.4.1.3 Back Sawing (Tangential, Flat or Slash Cut)

In this method the log is sawn so that the width of the board is tangential to the growth rings. The log is to be turned frequently to new positions for sawing to produce the tangential cut; this also allows the sawing around faulty parts of the log and separating sapwood from true wood with a minimum waste (Walton, 1974).

2.4.1.4 Quarter Sawing (Radial or Rift Cut)

In quarter sawing (also called sawing for grain); the saw actually splits the medullary rays, causing the rays to appear shiny or reflective. Quarter sawing is more of an art than plain sawing. Quarter sawing takes larger logs to saw this product, more production time in sawing each “quarter”, all of which equates to a premium price (Taylor, 2004). The quarter sawing pattern is a specialized cutting pattern that finds application with hardwoods as it is designed to show off the grains of decorative timbers (Todoroki and Ronnqvist, 1999). Quarter sawn boards are preferred for interior finish (mouldings, architraves, sash and door frames) and furniture as they retain their shape better than other cuts (Walton, 1974).

Quarter sawing takes more time and results in lower yields per log and narrower boards but it produces attractive boards that have a low susceptibility to drying deformities. However, the reduced volumetric recovery from quarter sawing is usually more than compensated for by higher prices for the sawn wood. It is important to note that during the sawing process the log is not slabbed initially. The log is basically sawn into quarters and each quarter is then vertically sawn into boards (Ontario Woodlot Association, 2000).

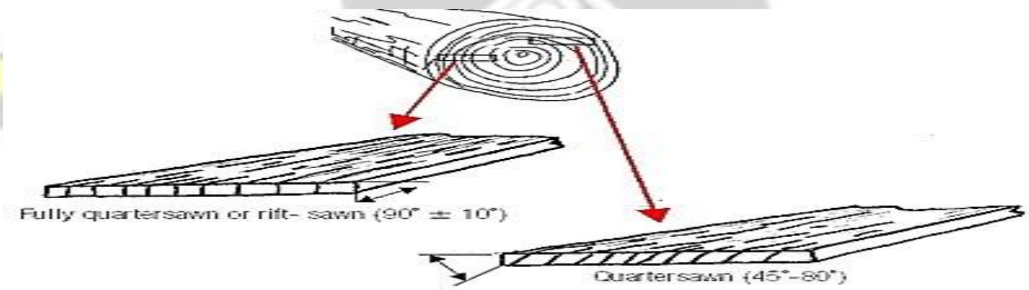


Plate 2.3 Location of quarter sawn and rift-sawn lumber in a log.

Source: Ontario Woodlot Association (2000).

2.4.1.5 Cant Sawing

This is a method of sawing which removes boards from the opposite log face in one sawing plane resulting in a cant, which is sawn into boards (Walker, 1993). Attah (1996) defines cant sawing as a method of sawing which involves making a first cut in such a way as to obtain a supporting face to the carriage. It is best suited for large diameter logs. It has the advantage of producing higher lumber recovery values due to less edging of timber and the use of fewer saw lines than "through and through" sawing.

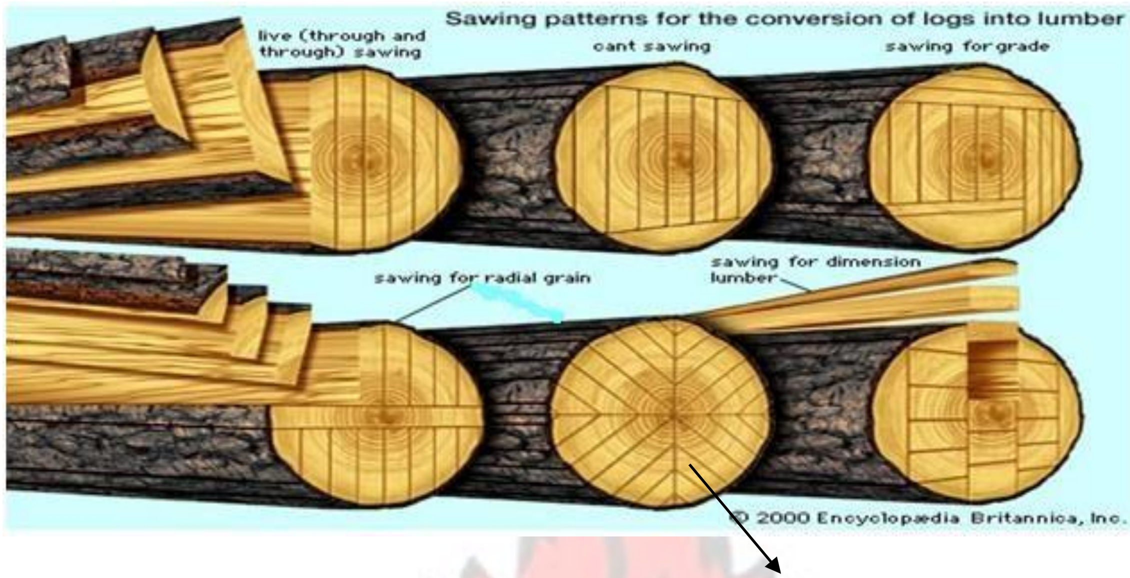


Plate 2.4 Some Sawing patterns

Source: Encyclopaedia Britannica (2000)

2.4.1.6 Wainscot Cutting

The heart centre or area of the pith of any given log is most likely to contain defects and is also subject to "heart shakes" so it is generally excluded from the higher wood grade. Wainscot cutting is a commonly used economical method of sawing logs to exclude the heart centre. In this method, the square edged timber is sawn through the heart into two halves and one or two boards taken off each side of the cut to eliminate any defects which may be present. It will be readily understood that the most efficient way to implement this method to yield a maximization of wood volume is to first ensure that the heart centre of the timber is indeed centered (Randle, 1995).

2.4.2 Yield or Recovery of Lumber

Log conversion efficiency in the sawmilling industry is commonly expressed as the yield or recovery of sawn wood milled from a given log (Adams, 2007). The mode of estimating lumber recovery is by dividing the total lumber product in cubic metres by total input volume. However, this does not take into account the size, quality or grade of the log in question (Akindenis *et al.*, 2012). Sawn wood recovery has been defined by Tsoumis (1991) as the proportion of the volume of acceptable quality lumber produced to the log input volume, calculated using the equation;

$RC\% = (VT/VL) \times 100$

Where: RC% = recovery in percent

VT = sawn wood volume (m^3)

VL = log volume (m^3)

When given values are placed in the formula, the recovery can be determined. The yield of the main products at a sawmill may be as low as 20% of the log, although more typically it is around 40-50%, even up to 70% in some cases (Noack, 1995). OfosuAsiedu *et al.* (1993) in their assessment of product yield and wood residues from seven selected indigenous species reported a mean yield of 46%. Lumber recovery in sawmills was 30-45% of the log input in a study research in Ghana (Nketiah *et al.*, 2001). Owusu *et al.* (2011) in comparative analysis of recovery efficiencies of some milling techniques in Ghana recorded lumber recovery between 28% and 64%. The lumber recovery values by Frimpong-Mensah (2004) was between 22% and 60% on freehand milling and Gyimah and Adu-Gyamfi (2009) on small to large scale enterprises was between 28% and 64%. Appiah (1983), in his analysis of effect of percentage sawn wood recovery on log cost and profitability of a saw mill, indicated that recovery is the most important item affecting cost

or revenue relationships of mills and therefore its profitability. Recovery determination becomes more important in situation of ever increasing log prices in
Ghana. He also reported an average lumber recovery or yield of 40.2% from a sawmill in Kumasi.

The wood processing industries cannot continue to expand simply by extracting more trees because the resource base is diminishing. To address this challenge, more efficient use of harvested trees is recommended. At present, there is far greater interest in minimizing waste and utilizing off-cuts in further processing to provide exports in shaped and machined mouldings, floorings, furniture components, dowels and other value added items (TEDB, 2007). The proportion of residue depends on factors such as the quality of the input log, the machinery used, the qualification, experience and motivation of the personnel, and the specifications of the main product (e.g. smaller dimensional timbers require more cutting, thus producing more sawdust) (Magin, 2001).

Brown (1995) listed the following as reasons to low recovery:

1. Improper positioning of logs on the log deck.
2. Too much slabbing, quarter sawing and boxing out defects.
3. Loses due to miscut cants and head rigs.
4. Inaccurate machine setting and general lack of skill on the part of machine operators and graders.
5. Lack of proper maintenance of machines leading to poor or wasteful sawing.
6. Poor saw doctoring coupled with use of old saws riddled with too many welded points.

7. Indiscriminate cross-cutting resulting from lack of skill and poor judgment in selecting export lumber.
8. Too much emphasis on setting high export standards at the expense of local recovery.

The Ministry of Land and Forestry (1996) identified out-dated and inefficient equipment as a characteristic feature of the Ghanaian wood processing industries. With the modernization in sawmilling technology and machinery, it has become increasingly difficult for millers to obtain spare parts for the out-dated equipment.

Damodaran (1996) remarked that, the right decision on the best opening face and cutting pattern, machine alignment, guide setting, simple attachments to machines and proper saw doctoring can invariably bring about improvements to sawn timber recovery and quality. Williston (1981) brought out four primary requirements for breakdown of a log to yield maximum lumber recovery. The four requirements are that:

- The log geometry must be known first before sawing begins.
- The position of the log must be known in relation to the cutting system and the geometry of the log itself.
- The log must be held firmly and transported forward along a predetermined path, usually in a straight line.
- The cutting system must be capable of generating thin straight cuts with relatively smooth surface.

An improved lumber recovery is an indication that mill productivity is being improved accordingly. Improvement in the efficiency of conversion is the one way that a saw miller increases revenue for his operation and the nation. Cooper (1994) indicated that revenue from sawing in a given quantity of logs will normally increase as yield increases. Factors affecting recovery of lumber are as follows:

2.4.2.1 Log Storage

Under proper storage conditions, logs can be kept for a long period of time. A major objective for log storage is to provide a buffer stock of raw materials in order to ensure continuous production in times of bad weather or unreliable log transport system (Cooper, 1994). Under poor storage conditions, logs can deteriorate through the drying and cracking of ends, development of blue stains (especially in the case of „white" species), decay and oxidation stains, attack by insects, development of undesirable odours and increased porosity due to attack by bacteria. Log end drying and splits can occur with susceptible species like dense hardwoods (*Cylicodiscus gabunensis* and *Entandrophragma angolense*), when the sun falls directly on the log ends. Blue stains and mould can occur in a week to ten days in the sapwood of light coloured species (e.g. *Pterygota macrocarpa* and *Triplochiton scleroxylon*) stored in humid conditions. Decay generally requires weeks or months to develop. Insects may attack a log within hours of felling. To minimize insect attack, logs should be used within two weeks after felling or treated with an approved chemical or stored under water (Mahut, 1995). It is worth noting that poor log storage leads to lower recovery values since considerable portions of the defective-ridden logs are sawn off as waste thus increasing the percentage residue.

To avoid log waste in the log yard, Attah (1996), has recommended the following measures:

1. That, logs be sprayed with preservatives (insecticides, fungicides and/or fire retardants) to avoid the insect and fungal attacks and also reduce risk of fire.

2. That, sawing is done as soon as possible to avoid log degradation.
3. That, where logs are stored on land, sleepers are provided to prevent logs from coming into contact with the ground.
4. Yards should be well drained.
5. Yard should be covered with gravel or some other suitable material.
6. Different species and top diameters should be stored separately.
7. Log ends should be directed away from the sun to avoid cracks and splits
8. Log ends should be coated with paint or water sprinkled regularly to prevent end cracks and splits.

2.4.2.2 Log Defects

The quality and quantity of lumber produced in the sawmill depends to a great extent on the quality of the raw material (log) that is processed (Odoom, 2004). Defects according to Hoadlley (1980) are irregularities or abnormalities in wood that lower its strength, grade value or utility. The presence of defects in logs greatly affects the quality, volume of plank yield and volume of residue. The various wood defects tend to influence lumber quality and output to varying degrees.

Defects may be natural or artificial. Natural defects are those which are characteristic of the growing tree such as growth defects, grain irregularities and shake. Artificial defects are caused by careless handling, incorrect conversion and seasoning techniques and inadequate protection or preservation of the timber. The presence of these defects significantly reduces the conversion ratio of wood for aesthetical and structural purposes. Some defects which have adverse effect on volume yield include sweep, reaction wood, rotten heart, heart shake, splits, buttressing, insect attack, fungal stains and knots. The extent to which each of these affects recovery depends on the end use of the lumber being processed (Brown *et al.*, 1994).

2.4.2.3 Log Size (Diameter, Length, Taper)

Log size, both diameter and length, has also been found to affect sawn wood recovery and as a general rule, large diameter, long logs give a higher recovery. For logs in the range of 30 - 70cm in diameter, recovery rates have been seen to drop to about half when the log diameter is halved. Today, few millers of tropical hardwoods can secure logs as large as they had a decade ago. Tropical log diameters have been steadily decreasing and will continue to decrease even further in the future.

2.4.2.4 Log Bucking Practices

Williston (1988) defines bucking as the process of crosscutting long logs into shorter segments or bolts suitable for breakdown on a sawmill head rig with the objective of manufacturing log segments that will maximize lumber value. A more considerable bucking in the forest, which matches the log length requirements in the mill, could result in real savings in raw material and consequently a better economy (Mahut, 1995). The aim of any sawmill is to maximize profit through the combined effect of obtaining the highest yield of acceptable quality lumber produced and increased sales. Castaneda (1988) remarked that proper felling and bucking techniques improve sawmill productivity. It is during the bucking process that logs are actually given their grade and so value. It is said that bucking can either break a sawmill or make it highly profitable, and that it should always be done to generate the best possible grade (Ackah, 2004).

To avoid bucking waste, Attah (1996) suggested that as much as practicable, long logs that are cut in the forest for transport should be in multiples of the contract lengths. This means there is the need for mill production managers to liaise up with „bush" managers who need to be aware of specifications of products in contracts that have been approved. To maximize yield, logs are bucked to the longest straight lengths. Cutting a swept log in half will reduce sweep by 75% and not 50% as might be supposed, that is assuming sweep is consistent along the log length (Cooper, 1994).

2.4.2.5 Species characteristics of wood

Species characteristics, especially the percentage of sapwood, particularly if it is of a different colour and lower durability and strength compared to the heartwood, affects recovery (Adams, 2007). The percentage of sapwood in a log affects recovery since lumber is not expected to contain excessive sapwood. Sapwood is not usually durable and can be easily attacked by insects and fungi. During sawmilling, most of the sapwood is sawn off as slabs, hence the narrower the width of sapwood in a tree species, the better the recovery and vice-versa (Brown *et al.,* 1994).

Species that generally sweep has effect on recovery. It has been noted that, the greater the amount of sweep, the greater the amount of wood that will fall into the outer zone when sawing, and this can result in low lumber recovery (Arkoful-Mensah, 2006).

2.4.2.6 Rough Green Storage

Improper stacking techniques, environmental conditions, and inventory control cause most of the loss during rough green storage. All loads should be placed on bunks, and all stickers (when used) should be properly aligned in the load. Loads should be square, not leaning, so they do not spill; even in frequent spills of 10 to 20 boards worth $10 each can be expensive because the spilled boards get run over and ground into the dirt and mud of the mill yard. Physical damage due to poor use of lumber-handling equipment can also be costly. Both the environment and length of storage can cause degradation of rough green lumber, particularly those species tending to stain (Brown, Undated).

2.4.2.7 Quality and skills of personnel

According to Agyeman (1998), the skills, capabilities and motivation of personnel are always key factors when high production and good results in the industry are considered. Khumalo (1988) mentioned that the best machinery is worthless unless the people operating them know what exactly is expected of them. To avoid wasteful sawing practices, sawmill personnel skill is paramount.

2.4.2.8 Grading and Quality Control

Timber grading is the sorting or classifying of timber into quality groups for particular use (Vaughan *et al.*, 1966). Log grading is important because it helps buyers and sellers settle on a fair price for a load of logs. Log grades can be used to predict the proportion of high-quality lumber that will be produced from a piece log. Thus log grading can also be used to help measure sawmill efficiency. Quality is the degree of conformance with specification. Owusu-Bremang (1994) defines quality as “fitness for use”. A means for measuring and controlling quality of wood products is by measurements along the production line to ensure conformance. Quality control has been defined as a procedure of establishing acceptable limits of variation in size with finished products or services and of maintaining them within these limits (Burbidge, 1978). Constant vigilance is the bedrock of effective quality control practice.

Agyeman (1998) mentioned that graders in most mills tend to have no training and so the entire process becomes dependent more or less on their (graders) intuitive judgment.

However, Frimpong-Mensah (1999) stated that, training is an important element of quality control, since it is impossible to maintain and achieve quality control program without providing adequate training for personnel. Logs are priced according to their grades. Lumber are also priced according to their grades. Residue on the other hand, are not graded therefore it has no market price.

Log Grading Guidelines

Grading is based on the nature and importance of defects, relating to the shape of the log and structure of the wood and does not take into account, the physical, mechanical or chemical properties of the timber, such as the specific gravity and strength (Mensah, 1982), however, the logs shall be fresh and no opaque end coating are allowed. Logs are classified into three main grades (A, B and C) and two intermediate grades (A/B and B/C). According to Fordjour (1997) a grade A log must have straight and cylindrical bole. It should be free from visible defect, except such as are too slight to impair the conversion value of the log to an appreciable extent. A grade B log may permit bends and irregular shaped to a moderate extent; it may show defects at ends and sides which in the aggregate, impair the conversion value to a moderate extent. A grade C log comprises logs which do not qualify for inclusion in second grade. Each species must be considered as a separate entity and graded with the knowledge of its peculiarities (Mensah, 1982).

Lumber Grading Guidelines

The hardwood grading rules generally used throughout the country are those established by the National Hardwood Lumber Association (NHLA) (NHLA, 2011). These rules list the following grades in descending order of quality of lumber:

Prime

FAS - First and Seconds NO. 1C

- Number one common, and

NO. 2C - Number two common.

In **prime**, no piece in a bundle may have grain deviating by more than 5cm per running metre. In **FAS**, 20% of the pieces in a bundle may have grain deviating up to 15cm per running metre but 80% of the pieces may not have grain deviating more than 10cm per running metre. In **No. 1C**, 25% of the pieces in a bundle may have grain deviating up to 20cm per running metre but 75% of the pieces may not have grain deviating more than 15cm per running metre. In **No. 2C**, there is no limit to grain deviation (NHLA, 2011).

2.4.2.9 Type and size of products

The type and size of the final product affect sawn wood output. Cutting small dimension lumber means spending more time and effort on the breaking down process and also greater recovery losses to sawdust, edgings and trimmings. Rybitskii (1985) claimed that sawing of random length and widths favour higher recovery more than fixed dimensions. Random lengths allow the sawyer some flexibility which goes a long way to increase lumber yield.

2.5 The nature of wood

Wood is a matured xylem. Wood, an important multipurpose natural resource has lots of uses to which it is put to meet human needs (Kramer, 2006). Wood is 51% carbon, 42% oxygen, 6% hydrogen, 0.2% nitrogen, 0.05% sulphur and less than 1% of the other elements on a dry-weight basis (Emcon Associates, 1980). Wood is an organic, renewable material and therefore a sustainable resource unlike many other non-renewable materials (metals, minerals and petrochemicals). As reserves become ever more depleted, extraction of such material becomes increasingly difficult. Wood also offers the benefit of carbon sequestration i.e. growing trees extract atmospheric carbon dioxide (CO_2) which through the process of photosynthesis is converted into carbohydrate to support structural growth. Growing forests thus have the potential to act as a mechanism for countering the increasing global concentration of atmospheric CO_2, which has implications for climate change (TRADA, 2005). As a raw material, wood has no equal peers. Additionally, of the construction materials, concrete, plastic, steel, and wood, only wood is naturally renewable (Shmulsky, 2009).

"The unique nature of wood has made it a valuable material in every stage of human development. At early age, the baby rests in wooden court, plays with wooden toys, and learns to write on wooden slate and paper when he is of school age. On graduating from school he receives a paper certificate. If he is lucky to secure employment his salary is paid in paper currency. When he is old he uses a wooden walking stick, sleeps on wooden bed and when he dies the body is laid in wooden coffin. Thus, man depends on wood right from the cradle to the grave" (Fuwape, 2003).

2.6 Wood Residue

Waste from the industry point of view, is the failure to recover the value inherent in a given amount of raw material. Issues (2000), defines wastes as anything that is no longer useful and need to be gotten rid of. Chambers (1996) defined waste as rejected, useless, unneeded or excess to requirement.

Wood residue can be defined as all form of wood that cannot be marketed at a profit from a logging or manufacturing operation, under current economic conditions and at the current stage of technological development (Panshin *et.al.*, 1962 ; Shirek, 2007). Dost (1966) also defined wood residue as the remnant of the original raw material after the economic value has been removed. NISER (1974) defined wood residue as the pieces of materials that are lost from the process of harvesting up to when the final products (planks) have been taken. Wood residue actually turns into wood waste if no value is found or determined for it. Thus failure to recover the value inherent in a given amount of wood material turns it into waste.

Hence, wood residue may be regarded as negative product of wood processing. That notwithstanding, what is regarded as wood residue in the sawmill is an important raw material in other industries. It is good to look for new and promising means to utilize the large volumes of usable wood residues following wood manufacture. This will improve the economy of the forest industries and sustain the livelihood of the forest dependent communities as well as the environmental services that the natural forests provide. The benefits of such utilisation would expand beyond the removal of residue, however, the overall long-term management of the forest would be strengthened and also there will be less visual impacts created by the residue accumulation.

Wood residue has been broadly classified into two: avoidable and unavoidable residue (FAC, 1972). Unavoidable wood residues are those that cannot be avoided or prevented even where the saw kerfs are minimal and the mill workers are efficient. These include sawdust, inconvertible slabs and strips. Avoidable wood residues are caused by:

(i) lack of pre-inspection of trees and logs,

(ii) lack of adequate saw maintenance and

(iii) poor harvesting techniques;

Both avoidable and unavoidable wood residues generated during harvesting and conversion are enormous and, when pooled together, can be used in the production of other alternatives like charcoal, for electricity generation and other bio fuels (Akachukwu, 2000).

Wood industry residues can also be broadly classified into two major categories: Solids (slabs, edgings, off-cuts, veneer wastes and cores); and Fines (sawdust, planer shavings and sander dust). Solids accounted for 79% of the residues produced while sawdust accounted for the remaining 21% in a research conducted in Ghana (JOINT UNDP/WORLD BANK, 1988). In 1998, it was estimated that in Ghana, the sawdust generated in the mills alone was about 97,000 tonnes a year (Ocloo and Yeboah, 1980). According to Odoom (2004) sawdust accounts for about 20 -25% of the wood residue in a sawmill in Ghana. It was also stated that the sawdust waste is rarely used and creates environmental hazards besides being a fire hazard. It is usually disposed off by dumping or open burning.

According to FAO (1990), the possible utilization of wood residue as a commercial product, which will create a financial return must be given very serious consideration in the sawmill. There are various possibilities, which may be feasible and viable, but these are dependent on the types and volume of the residue material and the location of the mill.

2.6.1 Sources of wood residue

According to Magin (2001), residue is generated at all stages of the life of a piece of timber, from harvesting and sawmilling, through trading (e.g. timber merchants), secondary processing (e.g. furniture and joinery manufacture), to end of life disposal (e.g. demolition, disposal of old wood items). Panshin *et al.*, (1962) recognized that the major sources of residue were;

- Wood left in the forest after logging.
- Residual and waste wood generated in the manufacture of primary products such as lumber and veneer.
- Secondary production processes of planing and moulding operations as sawdust, flakes and chippings.

a. Logging residues

According to Adams (2007) recovery rates vary considerably depending on local conditions. A 50/50 ratio is often found in the literature e.g. for every cubic meter of log removed, a cubic meter of waste remains in the forest (including the less commercial species). Noack (1995) reported of a recovery rate of 56% with 44% being residues, consisting of stumps, branches, leaves, defected logs, off-cuts and sawdust. This figure may be higher if unwanted species that are felled intentionally or accidentally are considered as well.

b. Saw-milling residues

Recovery rates vary with local practices as well as species. After receiving the logs, about 12% is waste in the form of bark; slabs, edgings and trimmings amount to about 34% while sawdust constitutes another 12% of the log input (FAO, 1990). According to Agyeman (1998) and Ofosu-Asiedu *et al.*, (1988), the volume of sawdust is calculated by multiplying half the kerf width of the particular saw to the total surface area of all the lumber products (both graded lumber and residues of every log).

2.6.2 Possible commercial utilization of wood residues

Wood residues serve as raw material for a lot of production processes. Any wood - waste management strategy should follow the ″4R″ approach (i.e., reduce, reuse, recycle and recovery).

- Reduce: minimize waste during primary processing and storage.
- Reuse: use residue in downstream industries without changing its mechanical structure (e.g. off-cuts to the joinery).
- Recycle: use residue for reconstituted panel production such as Medium Density

Fibreboard (MDF).

- Recover: use residue as fuel.

When given a choice, it is always better to avoid the need to discard wood. Recycling is the process of turning waste back into raw materials so that it can be made into new items. Recycling means using things that have already been used, to make new things. Thus, it is the collection and separation of materials from the waste stream and subsequent processing to produce marketable products (Issues, 2000). Recycling timber is a practice that was popularized in the early 1990‟s as issue such as deforestation and climate change, prompted both timber suppliers and consumers to turn to more sustainable timber sources. Recycling timber is the most environmentally friendly form of timber production.

According to Brink (2003), the idea that wood can be recycled or reused and not hauled straight to the landfills, makes sense. A harsh reality for a lot of manufacturers is that, sending waste to landfills is far less expensive than finding ways to recycle it. Considering this, industry manufacturers who exert any form of effort towards greater environmental sound manufacturing process deserve commendation. The least favored option is sending material to a landfill (Bogart, 2004).

Currently, large volumes of wood residues are used in the generation of energy or the manufacture of secondary or value-added goods. However, significant amounts are still landfilled or burned without energy recovery. The development and adoption of alternative technologies will help reduce the quantity of wood residue that is wasted, which in turn will help minimize the potential for environmental degradation. A sound environment forms the basis for development (Samis *et al.*, 1999). Sawdust is the only residue in significant surplus for increasing off site residue utilization (Odoom, 2004). This is the fine particles of wood that are created when wood is cut with a toothed saw, because the saw creates a path by removing wood. It can range from dust size to clumpy grains. It is a breathing hazard (Lasode *et al.*, 2013). The use of sawdust for example can be regarded as a potential approach to environmental protection and long-term issues such as reforestation. However, there are some technical and economic constraints (eg. transportation and cost of processing) which limit the scope of its utilisation.

The economic disposal of wood residue (e.g. sawdust, short pieces of lumber and edging strips), is one of the most difficult problems within the wood products industry. Therefore, finding markets for these residues can be profitable. From a business standpoint, it is probably wisest to make a separate business to produce and market special products from the residues of the company. Such a separation also allows different management styles and techniques to be used and may prove helpful with financial liability. A separate company on a separate site would keep the sawmill or main manufacturing facility from becoming a retail yard and eliminate the associated safety concerns from having customers walking all over.

www.uwex.edu/ces/ag/sus/wood/pdfindex/wman10.pdf

Innovative means must be found to utilize surplus wood residue and appropriate disposal technology must be practiced. However, many of the processes which utilize wood residue are either capital intensive, or require wood residues in quantities that are in excess of the capabilities of a single wood processing company (TRADA, 1979). The inclusion of wood residues in raw materials used for the production of wood products means great savings on the amount of standing timber used.

2.6.2.1 Wood for energy in the forest products industry

The sawmill industry is one of the high energy consuming industries and the principal producer of wood residues in Ghana (FAO, 2005). There is a great potential of utilizing these residues for energy generation. By utilizing wood residue to produce renewable energy, the forest and timber industry can provide significant economic and social benefits while improving the health of forests to deliver a permanent reduction in carbon emissions without any negative impacts on ecosystem integrity or biodiversity. Wood residue is burned both to obtain heat energy and to alleviate possible solid residue disposal problems. Wood News (2008) published that in 2004, German forest product industries were able to meet 20% - 40% of their power requirement and 80% - 90% of their demand for heat from their own wood residues.

Mill residues are highly desirable wood fuel because they are available at the mills (no transportation cost), and they are often partially dried. It can be burned directly to produce steam and electricity. Cogeneration (or Combined Heat and Power [CHP]) is the term applied to the use of a fuel for simultaneous production of electrical or mechanical power and usable thermal energy e.g. steam or hot air (Samis *et al.*, 1999). Nowadays, cogeneration is considered as one of the most important techniques for achieving a more efficient usage of fuels, natural and financial resources savings and environmental protection (Koronakis, 2004).

In most sawmills, the sawdust is swept off the floor and discarded. But this byproduct can take the form of a co-product. According to Shirek (2007), the owners of the plywood mill, Tolko Industries Limited in Heffly Creek, British Columbia, were feeling the pinch of rising energy prices. Using natural gas to heat water for log conditioning and dryveneer processes was becoming more costly each year as the price of fuel climbed. The solution was in the mill itself. Instead of pilling that unused biomass into a compost heap, Tolko enlisted the help of Nexterra Energy Corporation to turn the residue into the energy needed to power portions of the mill.

Moisture content (MC) is the percentage of wood mass that is water (Simpkins, 2006). The amount of heat obtained from wood depends upon the moisture content. The energy efficiency of burning wood residue is directly related to the moisture content of the wood residue (Samis *et al.*, 1999). The drier the wood, the greater its heat yield (JUCA, 2011). Moisture content of the fuel has implications for how much of the energy embodied in biomass can be converted to useful work. A portion of the energy in the wood is used to eliminate the water. Consequently, lower moisture content implies higher energy content (Simpkins, 2006).

The water or moisture content (MC) of wood is generally expressed as

$$MC\% = \frac{(\text{Green mass} - \text{Dry mass}) \times 100}{\text{Dry mass}}$$

For some tree species, the MC can be as high as 200%. Considerable variation in MC can exist between trees of the same species and even between boards cut from the same tree (United States Forest Products Laboratory, 1974). The MC of sapwood (composed of living wood cells) is almost always higher than that of heartwood (dead wood cells) from the same tree (CFDC of Fraser Fort George, 2001).

2.6.2.2 Fuel for household use

Local residents and employees use off-cuts for cooking and backing. In other situations the off-cuts are converted to charcoal before being used in the house. Charcoal is formed when wood is heated to about 400ºC in the absence of air or in the presence of limited amount of air (FAO, 2008). Charcoal burns with a better flame than wood. In monetary terms, charcoal per unit mass is approximately ten times more valuable than wood (Walker, 1993). When the gas from the charcoal production process condenses, it forms a black liquid which is the wood vinegar. It improves soil quality and also accelerates the growth of roots, stems, tubers, leaves, flowers and fruits (FFTC, 2007).

2.6.2.3 Wood Pellets

Wood pellet is a source of stored green renewable energy produced from wood residue compressed into cylindrical shape and of uniform size. Wood pellets are made from small particles of wood residue from flour or sander dust, sawdust and chips that are dried, compressed, and extruded into pellets. A binder material such as polyethylene may be added to help the extrusion process, increase the energy value, and protect the pellets from breaking and absorbing moisture. Pellets may be used as fuel or pet litter (CFDC of Fraser Fort George, 2001).

2.6.2.4 Syngas

Syngas (synthesis gas) is a fuel produced from the gasification of wood and may be used as fuel for gas turbine engines or as fuel in boilers. It may also be used to produce gasoline, diesel fuel, and gasoline additives. The gasification process relies on the pyrolysis of wood or wood residue to generate syngas. Wood residues with lower moisture contents are preferred because less energy is required to evaporate the moisture prior to pyrolysis. However, high moisture content wood may also be gasified. Methanol is a liquid fuel produced from syngas (CFDC of Fraser Fort George, 2001).

2.6.2.5 Ethanol

Ethanol is a biofuel produced from biomass materials. It is a liquid fuel produced by extracting and converting starches and carbohydrates such as cellulose and hemicellulose from wood into sugars and fermenting the sugars to produce ethanol. Ethanol is concentrated prior to its use as a fuel. Wood residue must be in very small particles such as flour, sander dust, and fines in order to facilitate extraction of the cellulose and hemicelluloses (CFDC of Fraser Fort George, 2001).

2.6.2.6 Briquette production

A briquette (or briquet) is a block of flammable material used as fuel to start and maintain a fire. Common types of briquettes are charcoal briquettes and biomass briquettes. The name of a briquette comes from the material used in its manufacture, e.g. straw briquette from straw. Biomass briquettes are made from agricultural wastes and wood residues.

The biomass is finely shredded and moulded into suitable and easily combustible sizes. There are no binders involved in this process. The natural lignin in the wood binds the particles of wood together to form a solid. For charcoal briquettes, charcoal is grounded and mixed with a binding material to be able to mould it into shape. Generally, briquetting is done under high temperature and pressure. Burning a wood briquette is far more efficient than burning firewood. Moisture content of a briquette can be as low as 4%, whereas green firewood may be as high as 65% (Briquette Wikipedia, 2011).

2.6.2.7 Pulp and paper manufacture

Pulp is a fibrous material prepared by chemically or mechanically separating fibres from wood, fibrous crops or waste paper. The pulp is then used to produce paper. There are different methods of producing pulp for making different strengths and grades of paper. The most common methods are chemical, mechanical and semi-chemical pulping techniques (Brongers and Mierzwa, 2000). The economic viability of some sawmills depends on the fact that they have digesters that can use sawdust for pulp production. This will indirectly increase the yield of those sawmills (Samis *et al.,* 1999).

2.6.2.8 Wood-based panel manufacture

Good quality recycled woodchips and sawdust can be used in the manufacture of some wood-based panels (engineered wood products) such as chipboard or particleboard. Engineered wood is the term given to material derived from smaller pieces of wood that are bound together through a variety of glues, resins, and other chemicals to make a wood-like product. Wood-based panels are increasingly replacing solid timber in the UK market in a range of applications including furniture, flooring and shelving (Magin, 2001). When used properly, the composite products offer advantages over traditional solid wood products. Dimensional stability, uniformity, long spans, and engineered strength enhancement are just a few of such advantages (Shmulsky, 2009).

2.6.2.9 Packaging and packaging filler

Wood has long been used for fruit boxes and crates. Plastic products have substituted for wood over the years. However, with the growing environmental consumerism, wood packaging may again be the material of choice. Wood is a biodegradable packaging material. Packaging filler is used to protect items during shipping or transportation. Wood residue that can be used as filler includes sawdust and shavings (CFDC of Fraser Fort George, 2001).

2.6.2.10 Manufacturing "value-added" products or special products

A "lawn-carpet" made from wood fibre and textile, sown with lawn seed and a similar product that can be used like a geotextile to prevent erosion and distribute seeds for revegetation is a special product from wood residue (B.C. Ministry of Environment Land and Parks, 1995a).

Many of the by-products of lumber manufacturing can be the raw material for a variety of special wood products, including the needs of woodworkers. A list of some of the many potential products is provided in Table 2.1.

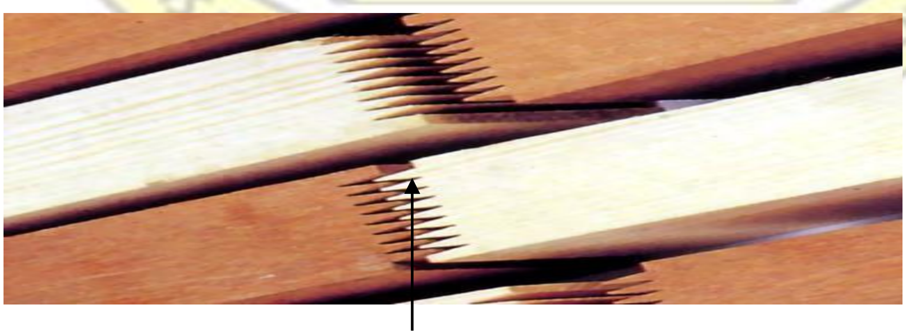
Table 2.1 Special products made from wood residues

Special Wood Products Potentially Made from Sawmill Residues		
Almond knockers	Flooring	Plaques and Trophies
Arrows	Game Calls	Playground Equipment
Bee Keeping Supplies	Bird Feeders	Baskets
Bird Houses	Clothes Hangers	Golf Club Heads
Knobs and Handles	Novelties and Toys	Clothespins
Signboards	Rulers and Yardsticks	Handles
Paint Stirring Sticks	Rolling Pins	Rollers
Canes/Walking Sticks	Carvings	Fence
Letters and Numerals	Hammer Heads	Rails
Snow Fences	Bowls	Butcher Blocks

Source: www.uwex.edu/ces/ag/sus/wood/pdfindex/wman10.pdf

2.6.2.11 Finger-jointed timber

A finger joint is a method of joining two or more separate pieces of wood together. It is named for its resemblance to interlocking fingers (Ryan, 2004). Off-cuts or small dimension timber can be finger-jointed into solid lengths, which can be used in place of lumber in a variety of functions. The joint is strong especially when used with good quality glue such as Polyvinyl acetate (PVA) also known as the woodworker‟s adhesive. If the joint is cut accurately the „fingers‟ should fit together without any gaps and the glue ensures that they are virtually indestructible. They are used for a wide range of products including jewellery boxes, cabinet construction and kitchen cupboards (Ryan, 2004).



Finger joint

Plate 2.5 Finger-joint (Source: www.wood-center.gr/enproduct.htm)

2.6.2.12 Wood-plastic composites

Wood-plastic composites are combinations of plastics with wood fiber, which takes advantage of the strength of wood fiber and the heat and water resistive properties of the plastic. It may be produced by either extrusion or mat-forming technologies. It may be used for dimensional lumber with increased weather and rot resistance for use in decks or playground equipment and complex moulding for the automotive industry (CFDC of Fraser Fort George, 2001).

2.6.2.13 Fill material in construction, landscaping and playground

Peatland is generally low lying and wet. To make more usable land, wood residue is often dumped in environmentally-unsuitable and wet locations such as low-lying and foreshore areas, gullies, ravines and wetlands. To allow construction of roads, highways, warehouses, industrial parks, houses and other structures on wetlands, wood residue is often dumped in huge quantities as a lightweight fill material rather than relying on the extraction of the peat and the use of an inert fill material (Samis *et al.*, 1999).

Woodchips can be reprocessed into an extremely effective playground surfacing material, or impact-attenuation surface. When spread to depths of one foot (30cm) playground woodchip can be effective at reducing impacts in falls up to 11 feet (3 meters). Playground woodchip is also an environmentally friendly alternative to rubber type playground surfaces. Groundcover is used on playgrounds or other areas that are accessible to the handicapped, including those in wheelchairs. Woodchips is one of the cushion materials that meet the requirements of the Americans with Disabilities Act and other impact safety laws (CFDC of Fraser Fort George, 2001). Wood residue is utilized as a foundation material in landscaped areas, pedestrian walkways, parks and trails.

Wood residue is sometimes placed on race tracks for snowmobiles or cars (Samis *et al.*, 1999).

2.6.2.14 Chunkrete

Chunkrete is a generic term to describe concrete produced using wood residue and/or flyash as the total or partial aggregate. Using wood as the aggregate in concrete reduces its density and increases its insulating and sound absorption properties (CFDC of Fraser Fort George, 2001).

2.6.2.15 Compost amendment

Composting is an aerobic biological treatment process which converts solid organic material into a stable humus at elevated temperatures (40 - 60^{o}C). Composting wood residue reduces the waste volume, detoxifies the waste and transforms the waste into a product that can be used as a soil amendment (Diehl and Stewart, 2000). Wood residue is a carbon source and “bulking” agent in composting operations. Shredded wood residue is used as a soil conditioner and amendment in composting, mulching and potting mixtures. Wood residue serves to retain moisture, retard erosion, inhibit weeds and hold warmth in the soil (Samis *et al.*, 1999).

2.6.2.16 Animal feed

Ruminants can easily derive energy from cellulose, a major component of wood. However, in most wood, the cellulose is surrounded by another chemical, lignin, that makes wood extremely indigestible. The use of wood for cattle intended for human consumption is questioned by some because of the concern for the safety of the meat www.uwex.edu/ces/ag/sus/wood/pdfindex/wman10.pdf

2.6.2.17 Animal bedding and litter

Animal bedding and litter are used for animals confined to stalls, pens or cages. It facilitates the disposal of excreta when mixed. Good quality shavings or sawdust are commonly used as animal bedding or on racetracks and gallops. Light coloured sawdust is preferred by some poultry farmers, because dark-coloured sawdust can contain substances which could cause tainting. The best wood residue material for the bedding and litter is a mixture of sawdust, planar shavings, chips and shredded wood. It should provide a cushion from the ground in stalls and pens and material for nesting or burrowing for caged animals. It must also be absorbent to help the collection and removal of faeces and urates. Wood residue used for bedding and litter should have a moisture content of 15 percent or less and should not contain non-wood materials or chemical contaminants (CFDC of Fraser Fort George, 2001). After use as bedding, the residue can be removed and used as manure for soil amendment.

2.6.2.18 Horticulture product

Wood residues are used for mulch manufacture or other horticultural products and agricultural uses. Chipped wood and bark are common mulches. A mulch of wood chips or similar materials, applied along the tree row, can help keep the trees" root zones cool and moist. Although wood chips mulch will not entirely control weeds, it will suppress them. Growers whose trees are mulched can attend to the few weeds within the rows on a more flexible schedule than growers who maintain a herbicide strip in the rows (www.city.kelowna.bc.ca/CM/Page437.aspx). Landscape mulch is used as a ground cover material to control weeds, prevent moisture loss in the soil, and for aesthetic purposes. Pigment can be added to the shredded wood to create a variety of coloured mulches. Popular colours include brown, black, and red as well as blue, green and yellow. Coloured mulch decomposes more slowly than conventional wood chips, does not change soil pH, and is environmentally safe (CFDC of Fraser Fort George, 2001).

2.6.2.19 Treatment of domestic sewage

According to Alderman (1998), wood residues can be combined with sewage to produce composts and assist in purification process. A pilot project to treat septic tank effluent with wood residue in Texas was implemented in 1993. Septic tank effluent was filtered through a layer of wood chips, reducing the total suspended solids (TSS) in the filtrate by 83 to 99%. This filtration process may serve as pre-treatment prior to treatment of the filtrate in a sewage treatment plant (Parten, 1994).

2.6.2.20 Potting soil

Potting soil is a nutrient enriched soil for optimum plant nutrition that is conditioned for best root growth and superior water retention. It will provide good water holding capacity while also providing appropriate drainage. Potting soil can be made from a mixture of 60% wood residue and 40% sand. The wood residue supplies the necessary organic matter for soil moisture and the sand provides proper drainage (CFDC of Fraser Fort George, 2001). Organic matter improves aggregate stability and soil structure, reduces erosion potential and provides energy for microorganisms (USDA, 1996).

2.6.3 Reasons for recycling wood residues

A greater proportion of wood residues go unutilized. The enormous wastage of wood in the various sawmills constitute a serious drain on the forest resource base and poses threat to sustainability (Agyeman, 1998). There are a number of important reasons to recycle wood residue. The following are some of the reasons:

2.6.3.1 Improving recovery of wood products and wealth creation

The timber industry is faced with a changing timber supply as the stand is converted to younger and smaller trees. The increased competition for raw materials and markets has resulted in the higher stumpage fees and a lower relative profit margin (Dost, 1966). This has resulted in the quest of the timber industry to improve on the recovery of products so as to make maximum profit. Also, trees provide oxygen (O_2) and thereby clean the atmosphere of carbon dioxide (CO_2) which is quite harmful to humans. The greater use of wood residues would have the effect of creating more wealth and usefulness through expansion of the total production of goods through more intensive management of the forest, without increasing the commodity drain (Tettey, 2009).

2.6.3.2 Landfill cost and space savings

Landfill costs can be avoided by recycling wood wastes, generating savings that, along with revenue from the sale of recovered wood waste materials, can be credited towards the processing costs associated with recovery. Again, wood residue frees up landfill space (SWANA, 2002).

2.6.3.3 Environmental benefits

Once wood residue is used, its volume will be reduced; therefore there will be little or no residue to pollute the surrounding communities. Using wood residue frees up landfill space, contributes to sequestering of carbon, reduces carbon dioxide emissions from processing virgin material, and contributes to sustainable use of natural resources (SWANA, 2002).

2.6.3.4 Natural resource benefits

Recovering and recycling wood from the waste stream result in the conservation of natural resources. By developing new markets for wood residues, forest owners have more opportunities to offset the costs of sustainable forest management and improve the overall health of the forests (Smith *et al.,* 2001).

2.6.4 Constraints to timber Re-use and Recycling

1. **Building Regulations and Material Specifications:** The construction industry is tightly regulated and specifications exist for most materials, especially those that

will be used in the structural and load-bearing functions. This may limit the use of recycled wood (Magin, 2001).

2. **Supply and Demand:** Supply by nature is sporadic and the availability of the right material at the right time in the right place for a specific construction or renovation project cannot be guaranteed. Thus one will have to establish what material is available before proceeding to detailed design and planning (Magin, 2001).
3. **Contamination:** Panel manufacturers require clean woodchips uncontaminated by preservatives, glues, metals or other substances including old wood-based panels, which are unsuitable for recycling because of the bonding resins they contain. A small amount of contaminant may render a whole consignment unusable (Magin, 2001).
4. **Dispersed Waste Sources:** Many of the sources of wood residue that might be appropriate for re-use and re-cycling are relatively small and dispersed, making the economics of waste collection by recycling companies marginal. Sorting residue until a sufficient quantity for collection or delivery to a recycler has accumulated, may not be possible in business with small premises, especially if mixed waste products are produced, each of which would have to be collected and stored separately (Magin, 2001).
5. **Capital Investment:** The equipment required for wood recycling (principally a chipper) is expensive to purchase. It is therefore only viable where a large, uncontaminated, reliable supply of recyclable timber and market for the woodchips are both assured (Magin, 2001).
6. **Awareness of Wood Recycling:** Wood re-uses and recycling is still in its infancy. Many companies, especially smaller businesses, are unaware of the options for

waste wood. Public concerns and prejudice over the quality and cleanliness of recycled materials may be a barrier to the sale of recycled timber products (Magin, 2001).

7. **Preservative Treated Wood:** Certain types of preservatives applied to some timber for external use, such as railway sleepers and electric poles, render wood unsuitable for recycling for panel manufacture, or for burning (the preservatives generate toxic emissions when burnt). (Magin, 2001).
8. **Lack of Data:** Lack of data, particularly affects the waste management industries, who have difficulty assessing the potential resource for recycling and hence the economic viability of a proposed scheme. The compilation of a reliable, comprehensive statistics on wood waste would be a valuable stimulus to wood recycling (Magin, 2001).
9. **Lack of Technological Knowhow:** Technology has developed by most of the developed countries in the world to effectively utilize wood residue that is generated in the various sawmills, however, in the developing countries, there are no technologies to help utilize these wood waste effectively (Ghann, 2002).

2.6.5 The impact of sawmill residue on the environment

Poor environmental practices have universally led to a degradation of the world's water, air and land resources. Wood residue poses several challenges to the environment and health of workers in the timber industries (Lasode *et al.*, 2013). When its utilization is low, saw millers use several crude ways to dispose the generated wastes within the vicinity and catchment areas of the sawmills, especially low-lying areas. Wood residues are also often dangerously heaped at different spots within sawmills and when it rains, the floor becomes slippery and make maneuverability around the sawmill extremely difficult (Lasode *et al.*, 2013). Over time, they become breeding spaces for worms and germs liberating obnoxious odour and exposing workers to unhygienic working environment (Dosunmu and Ajayi, 2002).

According to EPA (2013) backyard burning of wood waste can increase the risk of heart diseases, aggravate respiratory ailment such as asthma and emphysema, and cause rashes, nausea or headaches. Burning of wood waste also produce harmful quantities of dioxins, a group of highly toxic chemicals that settles on crops and in water ways, where they eventually wind up in our food and affect our health. National and international environmental protection authorities are continually refining policies, regulation, practices and procedures with the aim of minimizing the risk of environmental harm as part of transitioning to a sustainable future. It is often a much more expensive proposition to try to mitigate environmental impacts after they have occurred than to plan ahead and avoid them (EPA, 2013). Waste has to be disposed of in an environmentally acceptable manner. Recycling wood residue saves space, hence extending the life of landfills.

2.6.5.1 The impact of sawmill residue on water quality

Wood-residue sites should ideally be located in areas where evapotranspiration rates are greater than rainfall rates. The site should be down-gradient (i.e. downhill) from wells and watercourses. Siting is generally not acceptable within areas that typically collect surface water or groundwater and where such waters drain into fish habitat (Samis *et al.*, 1999).

Water pollution is the contribution of substances from human activities that may adversely affect a desired use of water (Alberta Government, 2006). Pollution of water ways by organic discharges poses a serious threat to inland waters. Manufacturing operations that produce raw wood, such as sawmills, paper mills and furniture manufacturers are the major source of pollution in the water ways. FAO (1991) emphasized that wood residue often contain significant amount of organic substances which produce adverse effects on the physical, chemical and biotic properties, as well as indirectly affecting human health. Therefore wood residue should be properly managed to reduce the negative impact on the environment such as leachate

2.6.5.2 The effect of wood residue on air quality

The approach to air quality needs to be risk-based taking into account all exposures along with the health status of the population for effective management measures (www.epa.sa.gov.au/xstd_files/Air/Report/le_fevre_report.pdf). Wood dust has several hazards associated with exposure to it in the workplace. In general, exposure to excessive amounts is considered to have an irritant effect on eyes, nose and throat in addition to pulmonary function impairment and is considered a human carcinogen. Wood dust becomes a potential health problem when, the wood particles, become airborne and are inhaled. Significant accumulations of fine particles of wood dust can also be a fire hazard in the workplace (www.osha.gov/SLTC/wooddust/index.html#eTools). Surplus wood residues are burned as refuse in the open, this results in air pollution problems because of smoke and fly ash (www.epa.gov/OCEPAterms/tterms.html).

2.6.5.3 Soil quality and the effect of wood residue on the soil

Soil quality is the capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health habitation (Merrington *et al.*, 2006). Healthy soils are vital to a sustainable environment. They store carbon, produce food and timber, filter water and support wildlife and the urban and rural landscapes. They also preserve records of ecological and cultural past (Merrington *et al.*,2006).

2.7 Wood residue decomposition

The continuous removal of nutrient through crop harvest results in decline of soil fertility. The current level of mineral fertilizer use in Ghana is very low as a result of increasing mineral fertilizer prices, however farmers in Ghana use less than 5kg/ha plant residue as fertilizer (Tetteh, 2004). Sawdust is the only wood residue in significant surplus for increasing off site residue utilization. It accounts for about 20 - 25% of the wood residue (Odoom, 2004). Sawdust could be used to meet crop nutrient requirements for improved crop production to relieve the resource-poor farmers of the burden of high cost of mineral fertilizers. However, there is not much information on their quality and decomposition rates.

According to Tetteh (2004), decomposition is the breakdown of organic residues by microorganisms into simple inorganic compounds, carbon dioxide and energy. Decomposition process prevents the unwanted accumulation of organic residues and facilitates the release of the nutrients held within these residues. Decomposition is a complex process regulated by the interactions between organisms (fauna and microorganisms), physical environmental factors (particularly temperature and moisture) and resource quality (lignin, nitrogen and condensed soluble polyphenol concentrations) (Swift *et al.*, 1979). They further stated that decomposition of organic material in the soil is a fundamental ecosystem process that maintains a continuous supply of nutrients to plants. Different wood species have different rates of decomposition since they are different anatomically.

The C/N and lignin/N ratios are estimates of the ease or otherwise of the decomposition of organic material. The quantity of lignin and cellulose in plant residue is also important in predicting rates of decomposition (Sanchez and Miller, 1986). Slow rates of decomposition are commonly observed with residues that are high in lignin and cellulose (Alexander, 1977). The C/N ratio of the organic material is the criterion used most often to predict net N immobilization or mineralization during residue decomposition (Trinsoutrot *et al.*, 2000). Other factors include the percentages of soluble C and N (Cogle *et al.*, 1989), lignin (Hofmann et al., 2009), and polyphenols (Chaves *et al.*, 2005).

2.7.1 Factors affecting the decomposition of wood residues in the soil

The rapidity with which a given organic amendment is decomposed depends on temperature, the supply of oxygen, moisture, and available minerals, the C/N ratio of the added material, the microbial population, the age and lignin content of the added residue, and the degree of disintegration.

2.7.1.1 Moisture

Adequate soil moisture i.e. about 60 - 80 % of the water-holding capacity of the soil is a must for the proper decomposition of organic matter. Too much moisture leads to insufficient aeration which results in the reduced activity of micro-organisms and there by checks the rate of decomposition (AgriInfo, 2011). Moisture is of central importance in the soil, controlling the overall level of microbial activity and hence the rate of decomposition. All soil biological and chemical activities are dependent on an adequate level of soil water. Tetteh (2004) observed that microbial activity is minimal under dry conditions and in Ghana, crop residues remain on the soil surface during most part of the dry season. This was in line with work done by Carson (1985) in Accra – Ghana, which showed that, leaf litter decomposition was greatest at the commencement of the wet season and insignificant during the dry season. Tetteh (2004) further stated that plant materials with high water holding capacity decomposed faster than low water holding capacity materials which decomposed at lower rates.

2.7.1.2 Soil pH

Soil pH measures how basic or acidic the soil is. Under acid conditions (pH 1 – 4), bacterial activity which is responsible for most of the decomposition of organic matter is greatly reduced (AgriInfo, 2011). Many plants prefer slightly acidic soils (pH 5 – 6). Microbial populations are highest in soils with a neutral pH (pH 7), Organic materials decompose faster in neutral or near-neutral soils (Tetteh, 2004), therefore, are more conducive to decomposition than acidic or alkaline soils.

2.7.1.3 Temperature

Temperature is one of the most important environmental factors determining how quickly natural materials are metabolized and subsequently mineralized. There is no single optimum temperature because the composition of and optimum temperatures for microbial species vary. In the temperature range of 5 - 30°C (41 - 86°F), decomposition of plant residue is usually accelerated with rising temperature. Maximum decomposition rates are reached within a range of 30 - 40°C (86° - 104°F). Above 40°C (104°F), decomposition rates generally decline (Alexander, 1977).

2.7.1.4 Soil fauna

Soil fauna, particularly earthworms and termites, are important as regulators of decomposition, nutrient cycling and soil organic matter dynamics; they directly and indirectly affect soil structure and hence aeration, water infiltration and water holding capacity (Anderson and Ingram, 1993).

2.7.1.5 Soil Oxygen

Good aeration is necessary for the proper activity of the microorganisms involved in the decomposition of organic matter. Oxygen supply is essential to aerobic micro-organisms, the primary agents in decomposition. Thus, reduction in air supply will result in reduced decomposition rates. Mainly, restriction of oxygen supply by water logging slows decomposition (AgriInfo, 2011).

2.7.1.6 C/N ratio

Organic matter from diverse plant-tissues varies widely in their C/N ratio. The optimum C/N ratio in the range of 20-25 is ideal for maximum decomposition. Thus, a low nitrogen content or wide C/N ratio results into the slow decomposition. (AgriInfo, 2011).

2.7.2 Wood residue synchrony in soil fertility

Soil Fertility is seen as the integration of plant nutrient demand, decomposition processes, soil fauna activities and their interaction with soil chemical and physical properties (Anderson and Ingram, 1993). According to Tetteh (2004) synchrony is the manipulation of inputs to enable the release of nutrients and their uptake by plants to concur.

According to Hagger *et al.* (1993) synchrony means timing of release of originally bound nutrients to coincide with crop demand, hence improving the efficiency of nutrient uptake by plants. Thus, synchrony is promoted by managing the timing, placement and quality of the organic material. In promoting synchrony, researchers make use of knowledge in the different rates of decomposition of plant residues due to differences in quality i.e. the total nitrogen content (Tetteh, 2004).

2.8 Biochar

According to Lehmann and Joseph (2009), biochar is the carbon-rich product obtained when biomass, such as wood or leaves is heated in a closed container with little or no available air. In more technical terms, biochar is produced by so-called thermal decomposition of organic material under limited supply of oxygen (O_2), and at relatively low temperatures (<700^{o}C). Biochar is carbonaceous material produced specifically for application to soil as part of agronomic or environmental management (Lehmann and

Joseph, 2009).

The stability of biochar is of fundamental importance in the framework of biochar use for environmental management. There are two reasons why stability is important; first stability determines how carbon (C) applied to the soil as biochar will remain sequestered in soil and how long it may influence emission of greenhouse gas and contribute to the mitigation of climate change. Conversion of biomass to biochar followed by application of biochar to the soil increases the resistance time of carbon (C) in the soil relative to the application of the same biomass directly to the soil, and therefore can be considered over particular timescales to result in a net withdrawal of atmospheric CO_2 (Lehmann, 2007).

Adding biochar to soil can be motivated by several aspects, such as:

- Improvement of soils;
- Mitigation of climate change;
- Reduction of off-site pollution; and
- Waste management on economically viable basis (Lehmann and Joseph, 2009).

Soils that are degraded by long-term continuous cultivation may benefit the most from biochar additions (Kimetu *et al.*, 2008). As a deliberate soil amendment, biochar is, in most cases incorporated within the soil, rather than just being added to the surface where wind and water erosion can transport biochar particles (Glaser *et al.*, 2002).

2.9 The economic assessment of sawmilling and wood residue

The principal objective of a sawmill is to make maximum profit from its input. The profit is simply estimated by the difference between revenues and expenses.

The total revenue = expected sales volume x expected average unit price per volume.

Also, Profit = (Lumber Price +Residue Price) – (Operational Cost + Log Cost).

According to Cooper (1994) logs may account for between 70 - 90% of all costs. Rappold (2006) demonstrated that raw material costs account for more than half of the manufacturing costs in a hardwood sawmill environment. Labour is usually the second largest item except in high mechanized mills. General overheads, depreciation and interest charges often form small part of costs in small sawmills. According to Gregerson and Contreras (1992) a project must be able to have benefits from production which exceeds cost of production.

Agyeman (1998) reported that in lumber production, though residue is considered as a by-product, the cost of the raw material and the cost of other elements of production such as labour, energy, machine maintenance and overhead costs make it imperative for some benefits to be accrued from the residues so generated. In the principle of cost-sharing, both the main end product (lumber) and the by-product (residues) contribute fairly to the total production cost. According to Nketiah *et al.* (2001), sawmill residue is between 3045% of the input volume, making its economic utilization important. This helps to reduce the pressure on the forest through reduced harvesting rate of fresh logs.

Cost benefit analysis is a procedure to judge whether the aggregate benefit of a venture is greater than its aggregate costs or vice-versa. Price (1989) stated that cost benefit analysis provides a means of evaluation which process would best ensure maximum utility and profits. Cash Flow Statement is a basic financial statement that summarizes information about the flow of cash into and out of a firm. Cash flows are useful in providing information on specific earnings and expenditures of the firm and help users evaluate their own prospective cash receipts and shows realistically the periodic cash effects of a firm"s operating activities (Agyeman, 1998).

2.9.1 Activity-based costing

Activity-based costing (ABC) is an accounting methodology, which "derives product costs as the sum of the activities that occur to make the product" (Deakin and Maher 1991). In an ABC method, production processes are identified and their cost structures analyzed in detail. Resources, activities, and cost drivers are defined for each process. Sensitivity as the basic principle of ABC states, activities consume resources, and that consumption causes costs. All processes have some common cost factors: machinery, buildings, and constructed ground cause interest costs and their value decrease annually; these have to be taken into account as capital costs in relevant processes (Liebster and Homer, 1989).

2.9.2 Cost-volume-profit analysis

The first step in determining if a sawmill is profitable, and can keep operating is the knowledge of what it costs to operate it. A cost-volume-profit analysis will link changes in operating costs, revenues, and profits to changes in the volumes of products sold. This type of analysis is useful for estimating the number of products that must be sold at a given price to produce revenue that will either equal or exceed purchasing, manufacturing, and distribution costs. The cost-volume-profit analysis technique is useful to make predictions regarding profit (Ainsworth and Deines, 2003).

CHAPTER THREE

3.0 THE AMOUNT AND TYPES OF WOOD RESIDUES GENERATED AT THE STUDY SAWMILLS

3.1 Introduction

Ghana has about 80% of its forest cover destroyed in less than 100 years (Forest Watch Ghana, 2008). The accelerated rate of population growth of 2.1% per annum (World Bank, 2015), and industrialization over the last few decades has created a demand for ever increasing quantities of wood products. The utilisation of wood products is based on a raw material which has long regeneration periods. The Forestry Department has established policies, regulations and management plans based on a forty-year felling cycle to encourage the utilization of the timber resource on sustainable basis (TEDB, 1994; Ghana Forest and Wildlife Policy, 2012). The continually increasing demand for wood cannot be met by overexploiting the forest. The solution to this problem could be a more efficient processing of wood into modern industrial units.

Gyimah and Adu-Gyamfi (2009) reported an average lumber recovery for small to large scale enterprises as 28% to 64% and Nketiah *et al.*, (2001) also reported of lumber recovery for sawmills as 30-45% of the log input, thus a higher level (about 60%) of residue.

According to FAO (1990), the possible utilization of wood residue as a commercial product, will create a financial return in the sawmills. Therefore there is the need for information on the availability, types and quantity of wood residue to enhance its effective utilisation.

3.2 Objectives

The specific objectives of the study were as follows:

- To find out the conversion efficiency of lumber in the study sawmills.
- To estimate the residues generated at the various machine centres of the study sawmills.
- To identify the various types of wood residues and their quantities during the study.

3.3 Materials and Methods

3.3.1 Description of study areas

There are three main regions in Ghana that are into sawmilling; Ashanti region, BrongAhafo region and Western region **(**TEDB, 2007). Ashanti and Brong-Ahafo regions were selected at random. There was a reconnaissance survey to identify the mills that were in active production. Five from each region were selected initially for the research, however, only two from each region responded positively to work with the researcher.

The major underlying factors considered in the choice of the various sawmills where the research was conducted were their willingness to accept the researcher, the relative ease of acquisition of information for the project and their regular production due to availability of logs throughout the study period. They were four in all; two from the
Ashanti region and two from the Brong-Ahafo region.

The four (4) timber industries which were considered are:

- Asuo Bomosadu Timber and Sawmill (A.B.T.S.)
- Ayum Forest Products Limited - Mim (AFPL)
- Bibiani Logs and Lumber Company (B.L.L.C.)
- Logs and Lumber Limited (L.L.L.)

For the sake of anonymity they were designated Companies A, B, C and D during the data collection.

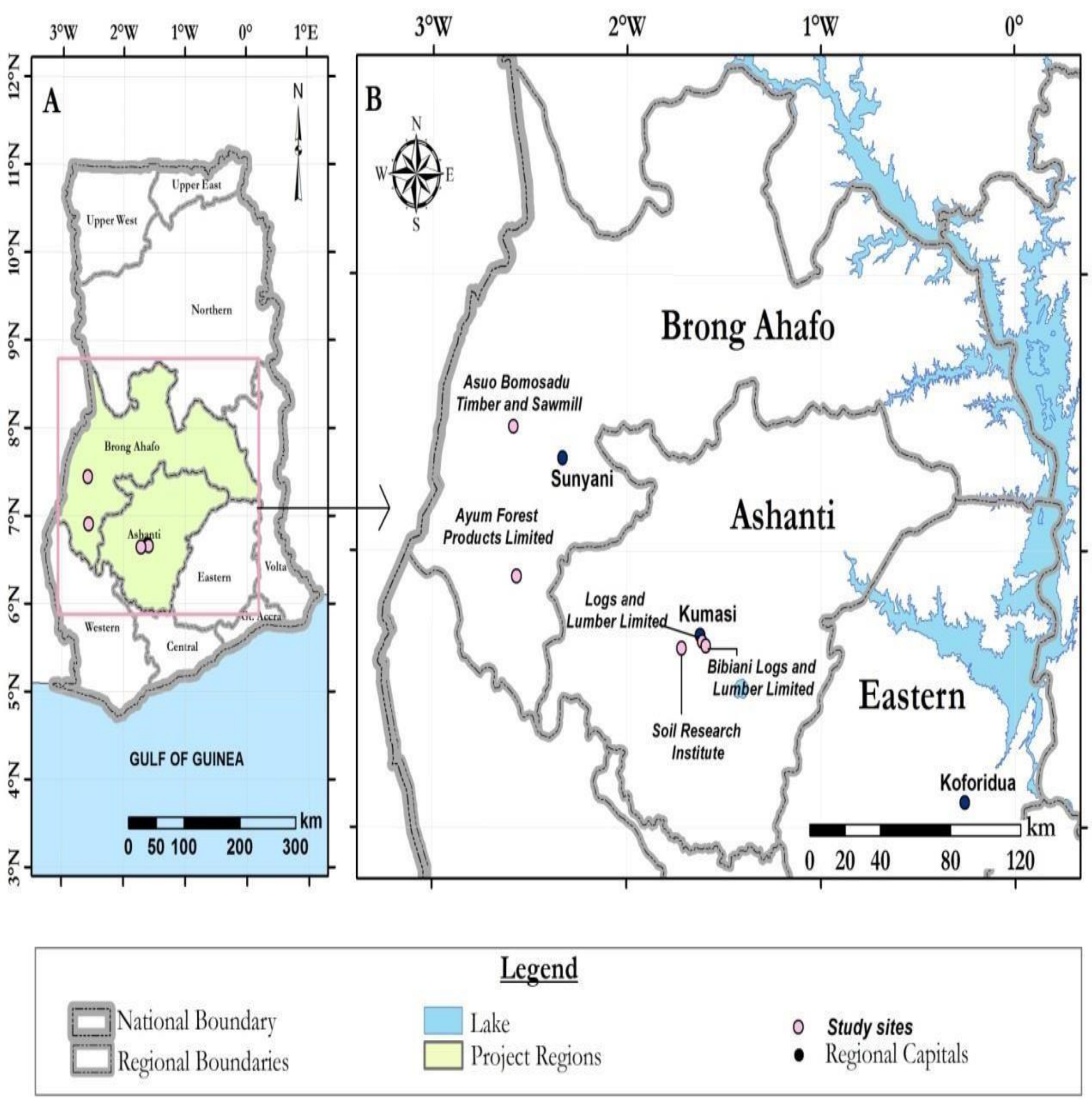


Figure 3.1 Map of Study Areas

The background of the selected study areas are as follows:

Asuo Bomosadu Timber and Sawmill (A.B.T.S.)

Asuo Bomosadu Timber and Sawmill Limited is located at Berekum in the Brong Ahafo Region of Ghana. Berekum is a Municipal town, located 32km from Sunyani, the Regional capital at the Western part of Brong Ahafo Region and lies between latitude 7º 27´ N and longitude 2º 35´ W. Asuo Bomosadu Timbers and Sawmill Limited is a private limited liability company which was established on 22nd October, 1980.

Ayum Forest Product Limited – Mim (AFPL)

Ayum Forest Products Limited - Mim (AFPL) was established in 1947 by a Ghanaian, Mr. Desmond Chartman, but its first production started in 1950. The company was known as Mim Timber Company (MTC). In the year 1974/75 it was taken over by the Government of Ghana on the bases of shareholder percentage ratio. In the year 2001, the Government then sold it to a Lebanese citizen, Naja David. The name was changed to Ayum Forest Product Limited – Mim (AFPL). AFPL, falls within the Asunafo North District in the Brong Ahafo Region of Ghana, within the high forest zones with a wet semi-deciduous vegetation type. It operates in more than fourteen (14) of Ghana‟s forest reserves.

AFPL is made up of four major processing departments, namely

- Sawmill department
- Veneer mill department
- Ply mill department

- Planning mill department (moulding department).

Bibiani Logs and Lumber Company (BLLC)

BLLC was established by Mr. B. M. Kufuor in 1946 as a logging company in Bibiani. The company expanded its operations and subsequently established a sawmill in Kumasi in 1960 to process timber for exports. BLLC is a wholly Ghanaian owned company and it owns concession totaling about 280 km^2 located at the Sefwi Wiawso area of the Western Region. Their source of timber is from a sustainably managed forest. They have developed a Forest Management Plan (FMP) and a Manual of Operation to ensure that the best practices are employed in the management of their forest.

BLLC has an installed capacity to produce the following per month:

- Lumber – 600m^3
- Rotary veneer/plywood - 1,200m^3
- Sliced veneer – 840,000m^2

The company presently ranks among the first six (6) timber firms in the country today in terms of operation (BLLC, 2012).

Logs and Lumber Limited (L.L.L.)

Logs and Lumber Limited (LLL) is in the Asokwa Sub-Metro of the Kumasi Metropolitan Area, in Ghana. It was incorporated as a private limited liability company on June 17, 1967 and commenced business on July 10, 1967. It is owned by Lebanese and exports most of its products to the EU. LLL has its own concessions covering almost 100,000 hectares. It is a sawmill purchased from Anglo African Timbers. Through expansion, the company has become one of the leading producers and exporters of wood products in Ghana.

3.3.2 Choice of Species

The species used for the study were selected after looking at the statistics of the most popular species sawn in the mills in the previous year. This was retrieved from the export document of the companies for 2011 (a range between 110.00m^3 - 130.00m^3 per month). The volumes of logs available at the beginning of the study and the immediate contract requirements were also considered. This was because when the researcher applied to do field work in the various mills, they all agreed based on the fact that the researcher would follow their production process and collect data whilst they did their normal work. However the researcher had the opportunity to collect data on a variety of species from the various sawmills.

The species used were *Cylicodiscus gabunensis* (denya), *Entandrophragma angolense* (edinam), *Pterygota macrocarpa* (koto) and *Triplochiton scleroxylon* (wawa). These four species were among the species which ranked high in the production processes of the study areas.

3.3.2.1 *Cylicodiscus gabunensis* (denya)

C. gabunensis of Mimosaceae Family (Oteng-Amoako, 2006) is a tree species which usually has a diameter range of 90-150cm. The heartwood is yellowish brown, often with a slight green tinge, on exposure darkening to reddish brown with a yellowish or greenish tinge; it is distinctly demarcated from the 5-8cm thick, pale pink sapwood. The grain is interlocked, texture moderately coarse. The wood is often slightly striped and lustrous, and has an unpleasant smell when freshly cut. The wood is very heavy and hard. At 12% moisture content, the density is 770 - 1,100 kg/m^3. The wood (trade names: okan, denya) is used for heavy construction including marine construction, sluice gates and bridges, heavy flooring, joinery, vehicle bodies, mine props, shipbuilding especially for decking, furniture including garden furniture, sporting goods, agricultural implements, railway sleepers, carving and turning (CIRAD, 2009).

3.3.2.2 *Entandrophragma angolense* (edinam)

E. angolense of Meliaceae family (Oteng-Amoako, 2006) has pale pinkish brown to pale reddish brown heartwood, slightly darkening upon exposure to deep reddish brown, and distinctly demarcated from the creamy white to pale pinkish, up to 10 cm wide sapwood. The grain is interlocked, texture moderately coarse and fairly even. Quarter-sawn surfaces are irregularly striped. The wood is medium weight, with a density of 510 - 735 kg/m³ at 12% moisture content. It is highly valued for exterior and interior joinery, furniture, cabinet work, veneer and plywood, and is also used for flooring, paneling, stairs, ship building, vehicle bodies and coffins. It is suitable for light construction, musical instruments, toys, novelties, crates and carvings (CIRAD, 2009).

3.3.2.3 *Triplochiton scleroxylon* (wawa)

T. scleroxylon belongs to the family Sterculiaceae (Oteng-Amoako, 2006). The heartwood is whitish to pale yellow, indistinctly demarcated from the sapwood, which is up to 15cm thick. The wood is lightweight, the density is 320 - 440 (- 490) kg/m³ at 12% moisture content. The wood is widely used for interior joinery, panelling, moulding, furniture, boxes and crates, sculptures, matches, pencils, peeled and sliced veneer for interior and exterior parts of plywood, fibre and particle boards, and blockboard. It is of great importance for house building, for beams, posts and planks, and is also used for roof shingles (CIRAD, 2011).

3.3.2.4 *Pterygota macrocarpa* (koto)

P. macrocarpa has a family name Sterculiaceae (Oteng-Amoako, 2006). It is local among various countries including Ghana, Cote d"ivoire, Nigeria, Gabon, Cameroun, United Kingdom and Germany. The tree has larger buttresses with a diameter range of 80 to 90cm. When sawn, it has a creamy white surface colour with an unpleasant odour. Its sapwood is not well distinct from the heartwood and it has straight or interlocked grain. It however has the tendency of becoming woolly during machining. *P. macrocarpa* can be used for wood frame house, interior paneling, sliced veneer, boxes and crates, furniture or furniture parts, interior joinery, moulding, fibre or particle board and seats (CIRAD, 2011).

3.3.3 Methods

The methods used in this study were devised to investigate the potential yield, value and recovery of bolts to green dimension lumber. The mill layouts in the various industries were similar but each was assessed separately. A total of one hundred and forty (140) bolts were selected for the research (Table 3.1).

Table 3.1 Number of bolts selected for the various species

SPECIES SELECTED	NUMBER OF BOLTS

***Cylicodiscus gabunensis* (denya)**	30
***Entandrophragma angolense* (edinam)**	30
***Triplochiton scleroxylon* (wawa)**	50
***Pterygota macrocarpa* (koto)**	30
TOTAL	**140**

The sawmilling operation was a continuous flow process in which bolts were cut into specific dimensions as they passed through the various machine centres. The sawing method used in all the sawmills was "sawing around" (sawing for grade) (Plate 2.4). The process generated residues (both coarse and fine) at all the machine centres. The data was collected based on the bolt measurements and their respective output. A pair of calipers was used to measure the saw thickness and the kerf width of the various saws employed by the machine centres of the various sawmills.

3.3.3.1 Log Yard Operations

All whole logs brought from the forest which were not suitable for slicing or peeling were transferred from the main log yard to the sawmill log yard. The logs were then bucked into bolts based on contract lengths using the chainsaw. An average tolerance of about 20cm was given on the bolts to make room for shrinkage, drying and handling defects in the case of production process. The bolts that were studied were selected at random during the production process to eliminate any bias associated with bolt size and defects. The species of the bolts were identified and recorded. The bolts were inspected for any visible defects and were graded into quality groups (Grades B and BC bolts were used). The quality of the bolts were comparable across the study sawmills. The bolts were given work numbers. A black permanent marker was used to write the work numbers on the bolts which were maintained throughout the production process so that the finished products of each bolt could be traced and this also helped to distinguish selected bolts from others.

In estimating the volume of sawn bolts, on each end of the bolt, the shortest diameter was taken and another which was perpendicular to the first was taken. An average diameter of the bolt (D_{av}) was given by adding the four diameters (two on each end) and dividing by four. This excluded the bark. A 5 metre steel tape was used in the measurement of the diameters while the lengths of the bolts were taken with a fibre tape of 20 metres. The average diameter (D_{av}) and the length of the bolt were used for the calculation of the bolt volume (m^3). Volume calculation of each of the bolts, before processing was carried out using the Smalian"s formula, which is also adopted by Timber Industry Development Division (TIDD).

$V_1 = 0.7854 D_{av}^2 L$ (m^3) **Equation 1** (Brack and Wood, 1997)

Where, V_1 = volume of bolt (m^3),

D_{av} = Average diameter of the bolts (m),

L = Bolt length (m)

0.7854 = Constant

The commonly used formulae for estimating the volume of logs are those of Huber, Smalian and Newton. Smalian's formula, requiring measurements at both ends of a log, is the easiest to apply which explains why it has the widest acceptance world-wide for log scaling (Brack and Wood, 1997).

The bolts were cleaned with hand brush to remove sand and mud from the bolts to avoid damage to the saw blades. The bolts were then transported to the band mill for further processing by the band saw.

3.3.3.2 Band Mill Operations

At the band mill, the bolts were inspected in order to fix the bolts in such a way that the best opening face was achieved. Thus, the side with the highest quality, which promised the highest volume and value was sawn first (Attah, 1996). The first two and last two slabs which contained majority of the sapwood were packed on one pallet, while the rest of the un-edged lumber were also packed on different pallets for further processing. Slabs are the first and last pieces of lumber removed when squaring a bolt (Martyr, 1973). The volume of the un-edged lumber was estimated by measuring the length, width and thickness at three points of the un-edged lumber and the average recorded. The pallets containing the un-edged lumber were then sent to the edger. The volume of the total residue at the band mill was given by the difference between the bolt volume and unedged lumber. This was made up of coarse residue (Plate 3.1) and fine residue (sawdust) (Plate 3.2). The volume of the solid residue was given by multiplying the length by thickness by width of each piece and finding the sum. The volume of the sawdust was estimated by subtracting the volume of the coarse residue from the total band mill residue.

Plate 3.1 Slabs from Production

Plate 3.2 Sawdust from Production

3.3.3.3 The Edger Operations

The edging process was done at the edger machine station where the bark (amount of wane) of the un-edged lumber was removed. The lumber that did not have square and parallel edges along the length of the board was passed through the edger. Lumber exiting the edger was smaller in width than when entering the edger and had two square edges in the lengthwise direction. The volume of the un-trimmed lumber was calculated.

Based on the contract, the lumber could be of fixed width or random width.

The formula for the volume of the fixed width lumber was given by;

$V_2 = [L \times W \times T]\, n$ **Equation 2**

Where, V_2 = Volume of sawn lumber (m^3)
L = Length (m)
W = Width (m)
T = Thickness (m)
n = Total number of lumber pieces obtained.

The random width lumber was tallied. The length, width and thickness, were measured and the volume was given by;

$V_2 = L \times T \times W_t$ **Equation 3**

Where,
V_2 = Volume of sawn lumber (m^3)
L = Length (m)
W_t = Total Width of lumber with similar thicknesses and lengths but different widths (m) T = Thickness (m)

The residue generated at this level was given by the difference between the un-edged and the edged lumber. This was made up of coarse residue (Plate 3.3) and fine residue (sawdust) Plate 3.2. The volume of the solid residue was given by multiplying the length by thickness by width of each piece and finding the sum. The volume of the sawdust was estimated by subtracting the volume of the coarse residue from the total edger residue.

Plate 3.3 Edgings from Production

Plate 3.4 Trimmings from Production

3.3.3.4 The Trimmer Operations

The function of the trimmer station was to cut the edged lumber to contract lengths. This process was done by a circular saw. The sawmills were arranged so that all materials went through the trimmer before exiting the sawmill. The volumes of the trimmed boards were given by equations 2 and/or 3. The total residue was given by the difference between edged lumber and the trimmed lumber. This was made up of coarse residue (Plate 3.4) and fine residue (sawdust) Plate 3.2. The volume of the solid residue was given by multiplying the length by thickness by width of each piece and finding the sum. The volume of the sawdust was estimated by subtracting the volume of the coarse residue from the total trimmer residue.

3.3.3.5 Total Recovery/Yield

The total recovery was given by the sum of the volume of the trimmed lumber. The percentage yield or percentage recovery was given by the ratio of the volume of the lumber to the volume of the input bolt in metres cube expressed in percentage as defined by Tsoumis (1991).

The Recovery (%) was calculated using the formula,

$$RR = \frac{V_2}{V_1} \times 100$$ **Equation 4** (Tsoumis, 1991)

Where, RR = Recovery (%)
V_2 = Volume of lumber obtained after conversion (m^3) V_1 = Volume of round bolts before conversion (m^3)

At all the sawmills, the lumber inspector employed by the sawmill, graded each piece of lumber.

3.3.3.6 Total Residue

The total volume of wood residue generated from the conversion of bolts was given by the difference between the bolt volume and the total lumber volume. This was calculated using:

$V_R = V_1 - V_2$ **Equation 5**

Where, V_R = Volume of wood residue (m^3)

V_1 = Volume of round bolts before conversion (m^3)

V_2 = Volume of lumber obtained after conversion (m^3).

The percentage residue was therefore calculated using the formula

Residue % $= \frac{V_R}{V_1} \times 100$ **Equation 6**

Where, V_R = Volume of wood residue (m^3)
V_1 = Volume of round bolts before conversion (m^3)

In order to offset the effect of the machine centres not fed with the same wood input volume, the percentage input volumes were what was considered for the comparison of the residues generated.

3.4 Data Analysis

Data obtained on the sawmill production process were subjected to Analysis of Variance (ANOVA) test to determine if there were any significant differences between the machine centres, then the Tukey post-hoc test was used to test the extent of the significant differences for conducting post-hoc tests on a one-way ANOVA.

3.5 Results

The input and output volumes, percentage recovery, percentage residue and volumes of residue generated at the various machine centres (bandmill, edger and trimmer) on bolts selected randomly from the study sites are summarized in Tables 3.2 – 3.23. The details on the bolt dimensions and volumes are shown in Appendices Ia – Ih.

3.5.1 Lumber Recovery and Residues generated at the Sawmills

The average lumber recovery at the four mills was 38.08% with residue forming 61.92% of the input volume. Both solid and fine residues were generated at the mill. The solid (coarse) residues were made of slabs, edgings and trimmings, while sawdust was the only fine residue identified. Tables 3.2 – 3.18 show the various percentages of lumber recovered and residues generated from input bolt volumes for the various species and at the various sawmills.

3.5.1.1 Yield results for Company A

Table 3.2 Yield results for *Triplochiton scleroxylon* at Company A

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3)		
			Coarse	sawdust	TOTAL
Band mill	46.670	35.144	7.200	4.326	**11.526**
Edger	35.144	21.860	12.733	0.551	**13.284**
Trimmer	21.860	16.263	5.493	0.104	**5.597**
TOTAL VOLUME OF RESIDUE (m^3)			**25.426**	**4.981**	**30.407**

Lumber Recovery % = $\frac{V_2}{V_1}$ x 100

Where, V_2 = Final volume of lumber obtained at trimmer (m^3),

V_1 = Volume of round bolts before conversion (m^3)

Lumber Recovery % = $\frac{16.263}{46.670} \times 100 =$ **34.85%**

Wood Residue % = 100 – Lumber Recovery %

= 100 – 34.85 = **65.15%**

Tables 3.2, 3.3 and 3.4 give details about the lumber recovery and wood residues for company A. Table 3.2 shows that the recovery percentage for *T. scleroxylon* was 34.85% and the residue was 65.15%.

Table 3.3 Yield results for *Cylicodiscus gabunensis* at Company A

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3)		
			Coarse	sawdust	TOTAL
Band mill	22.933	16.287	5.008	1.638	**6.646**
Edger	16.287	10.096	5.846	0.345	**6.191**
Trimmer	10.096	7.631	2.379	0.086	**2.465**
TOTAL VOLUME OF RESIDUE (m^3)			**13.233**	**2.069**	**15.302**

Lumber Recovery % = $\frac{7.631}{22.933} \times 100 =$ **33.27%**

Wood Residue % = 66.73%

Table 3.3 gives details about *C. gabunensis*. The recovery percentage was 33.27% and the residue was 66.73%.

Table 3.4 Yield results for *Cylicodiscus gabunensis* and *Triplochiton scleroxylon* at Company A

MACHINE TYPE	Input volume (m)	Output volume (m)	Residue volume (m^3)		
			Coarse	sawdust	TOTAL
Band mill	69.603	51.431	12.208	5.964	**18.172**
Edger	51.431	31.956	18.579	0.896	**19.475**

Trimmer	31.956	23.894	7.872	0.190	**8.062**
TOTAL VOLUME OF RESIDUE (m^3)			**38.659**	**7.050**	**45.709**

Lumber Recovery % = $\frac{23.894}{69.603} \times 100 =$ **34.33%**

Wood Residue % = 65.67%

Table 3.4 gives a summary yield of company A. Here the average recovery for Company A was 34.33% with residue of 65.67%. 84.58% of the total residue was coarse residue (slabs, edgings and trimmings) and the remaining15.42% was sawdust.

3.5.1.2 Yield results for Company B

Table 3.5 Yield results for *Triplochiton scleroxylon* at Company B

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3)		
			Coarse	sawdust	TOTAL

Band mill	34.292	28.815	3.474	2.003	**5.477**
Edger	28.815	18.366	10.021	0.428	**10.449**
Trimmer	18.366	13.961	4.344	0.061	**4.405**
TOTAL VOLUME OF RESIDUE (m^3)			**17.839**	**2.492**	**20.331**

Lumber Recovery % = $\frac{13.961}{34.292} \times 100 =$ **40.71%**

Wood Residue % = **59.29%**

Tables 3.5, 3.6 and 3.7 give details about the lumber recovery and wood residue for Company B. Table 3.5 was made up of *T. scleroxylon*. The recovery percentage was 40.71% and the residue was 59.29%.

Table 3.6 Yield results for *Cylicodiscus gabunensis* at Company B

MACHINE TYPE	Input volume (m^3)	Output voume (m^3)	Residue volume (m^3)		
			Coarse	sawdust	TOTAL
Band mill	30.435	21.710	6.919	1.806	**8.725**
Edger	21.710	13.879	7.416	0.415	**7.831**
Trimmer	13.879	10.580	3.215	0.084	**3.299**
TOTAL VOLUME OF RESIDUE (m^3)			**17.550**	**2.305**	**19.855**

Lumber Recovery % = $\frac{10.580}{30.435} \times 100 =$ **34.76%**

Wood Residue % = **65.24%**

Table 3.6 shows that the recovery percentage for *C. gabunensis* was 34.76% and the residue was 65.24%.

Table 3.7 Yield results for *Cylicodiscus gabunensis* and *Triplochiton scleroxylon* at Company B

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3)		
			Coarse	sawdust	TOTAL
Band mill	64.727	50.525	10.393	3.809	**14.202**
Edger	50.525	32.245	17.437	0.843	**18.280**
Trimmer	32.245	24.541	7.559	0.145	**7.704**
TOTAL VOLUME OF RESIDUE (m^3)			**35.389**	**4.797**	**40.186**

Lumber Recovery % = $\frac{24.541}{64.727} \times 100 =$ **37.91%**

Wood Residue % = **62.09%**

Table 3.7 which is a summary yield of Company B showed that the average recovery for company B was 37.91% with residue of 62.09%. 88.06% of the total residue was coarse residue (slabs, edgings and trimmings) and the remaining 11.94% was sawdust.

3.5.1.3 Yield results for *Triplochiton scleroxylon*

Table 3.8 Yield results for *Triplochiton scleroxylon* at Companies A and B

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3)		
			Coarse	sawdust	TOTAL
Band mill	80.962	63.959	10.674	6.329	**17.003**
Edger	63.959	40.226	22.754	0.979	**23.733**
Trimmer	40.226	30.224	9.837	0.165	**10.002**

TOTAL VOLUME OF RESIDUE (m^3)	43.265	7.473	50.738

Lumber Recovery % = $\frac{30.224}{80.962} \times 100 =$ **37.33%**

Wood Residue % = **62.67%**

Table 3.8 which is a summary yield of *T. scleroxylon* shows that the average recovery was 37.33% with residue of 62.67%. 85.27% of the total residue was coarse residue (slabs, edgings and trimmings) and the remaining 14.73% was sawdust.

3.5.1.4 Yield results for *Cylicodiscus gabunensis*

Table 3.9 Yield results for *Cylicodiscus gabunensis* at Companies A and B

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3) Coarse	sawdust	TOTAL
Band mill	53.368	37.997	11.927	3.444	**15.371**
Edger	37.997	23.975	13.262	0.760	**14.022**
Trimmer	23.975	18.211	5.594	0.170	**5.764**

TOTAL VOLUME OF RESIDUE (m^3)			**30.783**	**4.374**	**35.157**

Lumber Recovery % = $\frac{18.211}{53.368} \times 100 =$ **34.12%**

Wood Residue % = **65.88%**

Table 3.9 is a summary yield of *C. gabunensis.* The average recovery was 34.12% with residue of 65.88%. 87.56% of the total residue was coarse residue (slabs, edgings and trimmings) and the remaining 12.44% was sawdust.

3.5.1.5 Yield results for Company C

Table 3.10 Yield results for *Pterygota macrocarpa* at Company C

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3)		
			Coarse	sawdust	TOTAL
Band mill	33.127	24.680	5.766	2.681	**8.447**
Edger	24.680	15.746	7.722	1.212	**8.934**
Trimmer	15.746	11.870	3.760	0.116	**3.876**
TOTAL VOLUME OF RESIDUE (m^3)			**17.248**	**4.009**	**21.257**

Lumber Recovery % = $\frac{11.870}{33.127} \times 100 =$ **35.83%**

Wood Residue % = **64.17%**

Tables 3.10, 3.11 and 3.12 give details about the lumber recovery and wood residue for Company C. Table 3.10 shows that the recovery percentage for *P. macrocarpa* was 35.83% and the residue was 64.17%.

Table 3.11 Yield results for *Entandrophragma angolense* at Company C

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3) Coarse	sawdust	TOTAL
Band mill	30.999	24.052	5.324	1.623	**6.947**
Edger	24.052	16.210	7.490	0.352	**7.842**
Trimmer	16.210	13.922	2.189	0.099	**2.288**
TOTAL VOLUME OF RESIDUE (m^3)			**15.003**	**2.074**	**17.077**

Lumber Recovery % = $\frac{13.922}{30.999} \times 100 =$ **44.91%**

Wood Residue % = **55.09%**

Table 3.11 gives details about *E. angolense.* The recovery percentage was 44.91% and the residue was 55.09%.

Table 3.12 Yield results for *Entandrophragma angolense* and *Pterygota macrocarpa* at Company C

MACHINE TYPE	Input volume (m)	Output volume (m)	Residue volume (m^3) Coarse	sawdust	TOTAL
Band mill	64.126	48.732	11.090	4.304	**15.394**
Edger	48.732	31.956	15.212	1.564	**16.776**

Trimmer	31.956	25.792	5.949	0.215	**6.164**
TOTAL VOLUME OF RESIDUE (m³)			**32.251**	**6.083**	**38.334**

Lumber Recovery % = $\frac{25.792}{64.126} \times 100 =$ **40.22%**

Wood Residue % = **59.78%**

Table 3.12, a summary yield of company C showed that the average recovery for company C was 40.22% with residue of 59.78%. 84.13% of the total residue was coarse residue (slabs, edgings and trimmings) and the remaining15.87% was sawdust.

3.5.1.6 Yield results for Company D

Table 3.13 Yield results for *Pterygota macrocarpa* at Company D

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3)		
			Coarse	sawdust	TOTAL
sBand mill	28.341	21.568	4.597	2.176	**6.773**
Edger	21.568	14.851	6.310	0.407	**6.717**
Trimmer	14.851	11.451	3.332	0.068	**3.400**
TOTAL VOLUME OF RESIDUE (m^3)			**14.239**	**2.651**	**16.890**

Lumber Recovery % = $\frac{11.451}{28.341} \times 100 =$ **40.40%**

Wood Residue % = **59.60%**

Table 3.14 Yield results for *Entandrophragma angolense* at Company D

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3)		
			Coarse	sawdust	TOTAL
Band mill	23.098	17.840	3.721	1.537	**5.258**
Edger	17.840	11.727	5.655	0.458	**6.113**
Trimmer	11.727	9.472	2.157	0.098	**2.255**
TOTAL VOLUME OF RESIDUE (m^3)			**11.533**	**2.093**	**13.626**

Lumber Recovery % = $\frac{9.472}{23.098} \times 100 =$ **41.01%**

Wood Residue % = **58.99%**

Tables 3.13, 3.14 and 3.15 give details about Company D. Table 3.13 was made up of *P. macrocarpa*. The recovery percentage was 40.40% and the residue was 59.60%. Table 3.14 shows that the recovery percentage of *E. angolense* was 41.01% and the residue was 58.99%.

Table 3.15 Yield results for *Entandrophragma angolense* and *Pterygota macrocarpa* at Company D

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3)		
			Coarse	sawdust	TOTAL
Band mill	51.439	39.408	8.318	3.713	**12.031**
Edger	39.408	26.578	11.965	0.865	**12.830**
Trimmer	26.578	20.923	5.489	0.166	**5.655**
TOTAL VOLUME OF RESIDUE (m^3)			**25.772**	**4.744**	**30.516**

Lumber Recovery % = $\frac{20.923}{51.439} \times 100 =$ **40.67%**

Wood Residue % = **59.33%**

Table 3.15 which is a summary yield of company D showed that the average recovery for Company D was 40.67% with residue of 59.33%. 84.45% of the total residue was coarse residue (slabs, edgings and trimmings) and the remaining15.55% was sawdust.

3.5.1.7 Yield results for *Pterygota macrocarpa*

Table 3.16 Yield results for *Pterygota macrocarpa* at Companies C and D

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3) Coarse	sawdust	TOTAL
Band mill	61.468	46.248	10.363	4.857	**15.220**
Edger	46.248	30.597	14.032	1.619	**15.651**
Trimmer	30.597	23.321	7.092	0.184	**7.276**
TOTAL VOLUME OF RESIDUE (m^3)			**31.487**	**6.660**	**38.147**

Lumber Recovery % = $\frac{23.321}{61.468} \times 100 =$ **37.94%**

Wood Residue % = **62.06%**

Table 3.16 is a summary yield of *P. macrocarpa.* The average recovery was 37.94% with residue of 62.06%. 82.54% of the total residue was coarse residue (slabs, edgings and trimmings) and the remaining 17.46% was sawdust.

3.5.1.8 Yield results for *Entandrophragma angolense*

Table 3.17 Yield results for *Entandrophragma angolense* at Companies C and D

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3) Coarse	sawdust	TOTAL
Band mill	54.097	41.892	9.045	3.160	**12.205**
Edger	41.892	27.937	13.145	0.810	**13.955**
Trimmer	27.937	23.394	4.346	0.197	**4.543**
TOTAL VOLUME OF RESIDUE (m^3)			**26.536**	**4.167**	**30.703**

Lumber Recovery % = $\frac{23.394}{54.097} \times 100 =$ **43.24%**

Wood Residue % = **56.76%**

Table 3.17 is a summary yield of *E. angolense.* The average recovery for *E. angolense* was 43.24% with residue of 56.76%. 86.43% of the total residue was coarse residue (slabs, edgings and trimmings) and the remaining13.57% was sawdust.

3.5.1.9 Yield results for all species

Table 3.18 Yield results for all species (*Cylicodiscus gabunensis* (Denya), *Entandrophragma angolense* (Edinam), *Triplochiton scleroxylon* (Wawa) and *Pterygota macrocarpa* (Koto)) at the four Companies

MACHINE TYPE	Input volume (m^3)	Output volume (m^3)	Residue volume (m^3) Coarse	sawdust	TOTAL
Band mill	249.895	190.096	42.009	17.790	**59.799**
Edger	190.096	122.735	63.193	4.168	**67.361**
Trimmer	122.735	95.150	26.869	0.716	**27.585**

TOTAL VOLUME OF RESIDUE (m^3)	**132.071**	**22.674**	**154.745**

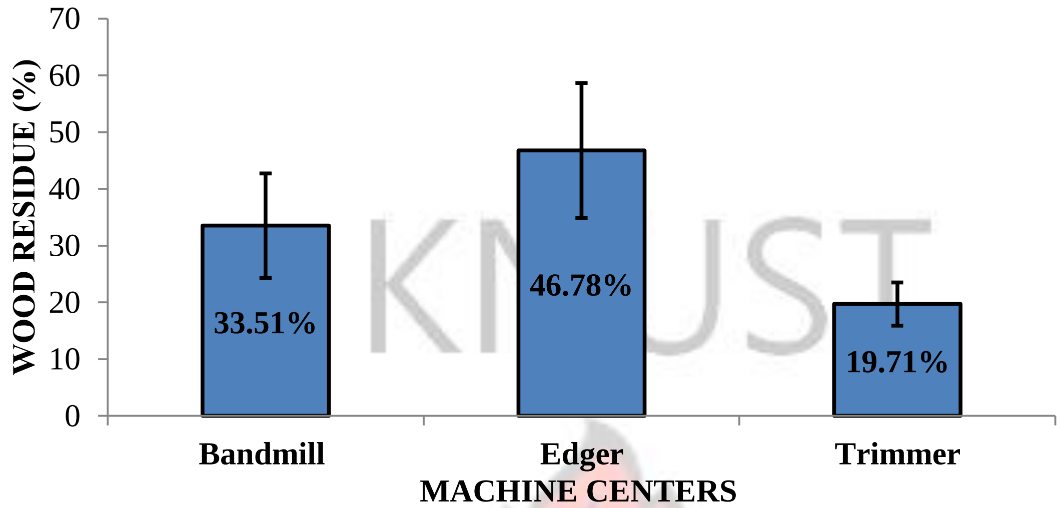
Lumber Recovery % = $\frac{95.150}{249.895} \times 100 =$ **38.08%**

Wood Residue % = **61.92%**

Table 3.18 is a summary result for all the four species. The total volume residue generated was 154.745m^3. The band mill was made up of 42.009m^3 coarse residue (slabs) and 17.790m^3 sawdust. The edger was made up of 63.193m^3 coarse residue (edgings) and 4.168m^3 sawdust; and the trimmer was made up of 26.869m^3 coarse residues (trimmings) and 0.716m^3 sawdust. The total sawdust of the production process was 22.674m^3. The production process produced four types of residues: slabs constituted 27.15% of residues, edgings constituted 40.84% of residues, trimmings 17.36% of residues and sawdust 14.65% of residues. The total input volume was 249.895m^3 with recovery of 38.08% and 61.92% residue. With reference to the input volume, lumber constituted 38.08%, slabs 16.81%, edgings 25.29%, trimmings 10.75% and sawdust 9.07%.

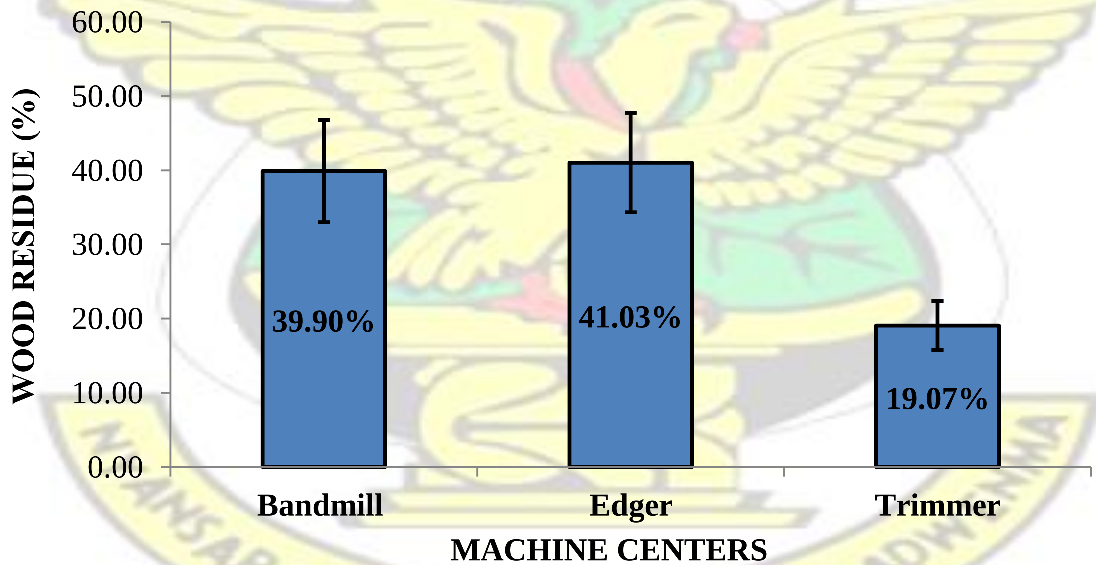
3.5.2 Residues generated at the various Machine Centres

Each of the machine centres namely; bandmill, edger and trimmer generated different quantities of residues that added up to give the overall residue generated. Figures 3.6 – 3.14 are bar charts that compare the residues generated as percentage of their total residue volumes for the various species and at each of the mills.



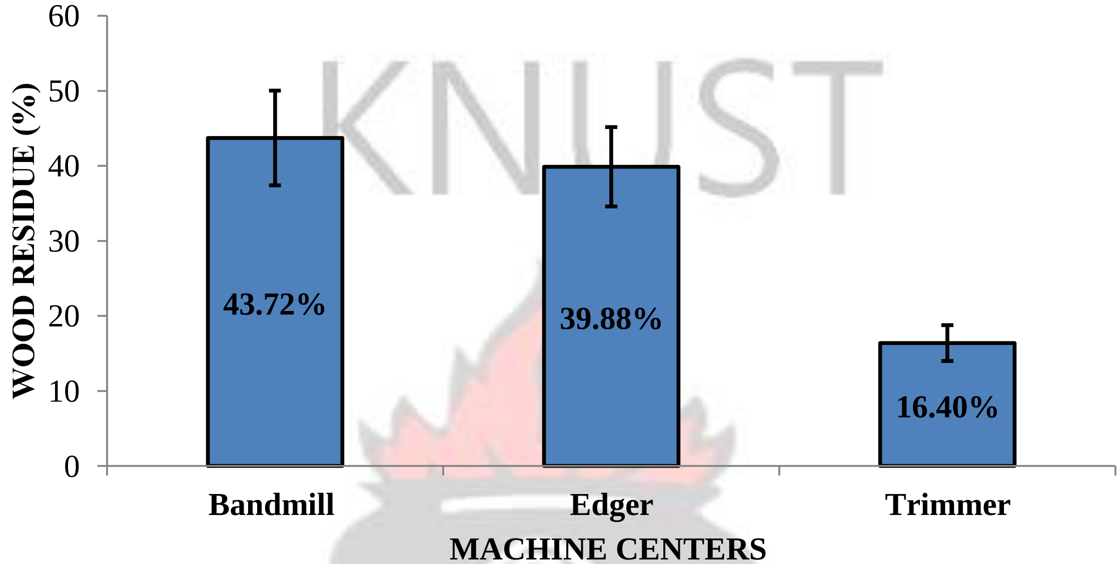
Error bars at 95% Cl

Figure 3.2 Residues generated from *Triplochiton scleroxylon* as a percentage of total residue volume



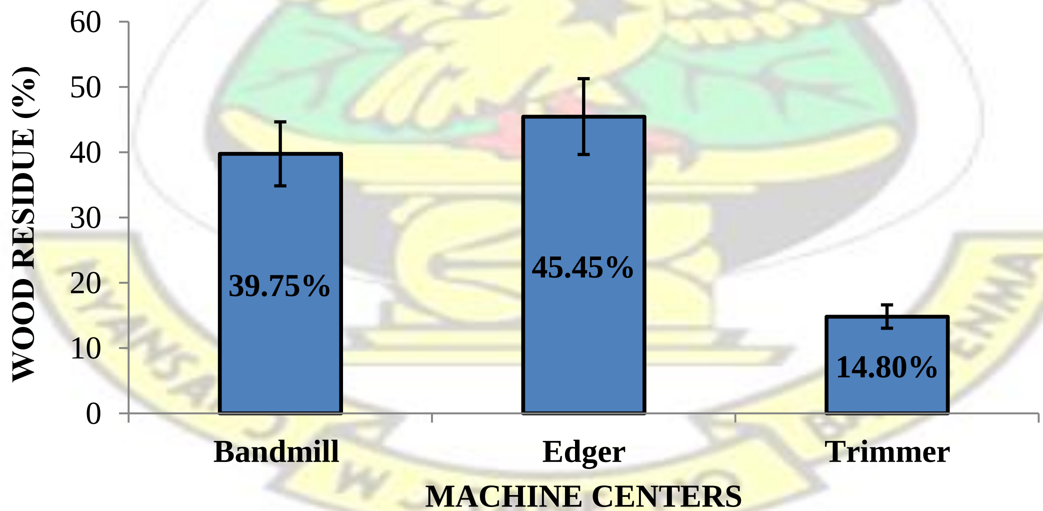
Error bars at 95% CL

Figure 3.3 Residues generated from *Pterygota macrocarpa* as a percentage of total residue volume



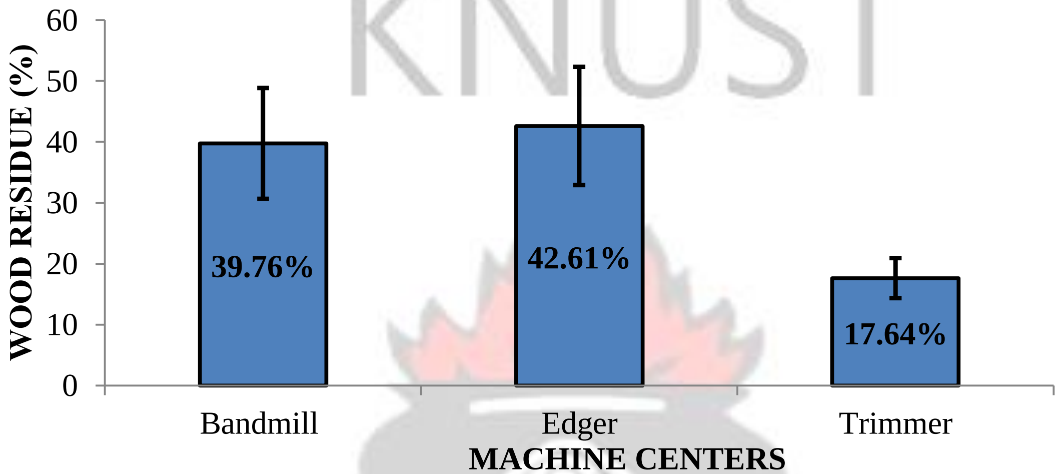
Error bars at 95% CL

Figure 3.4 Residues generated from *Cylicodiscus gabunensis* as a percentage of total residue volume



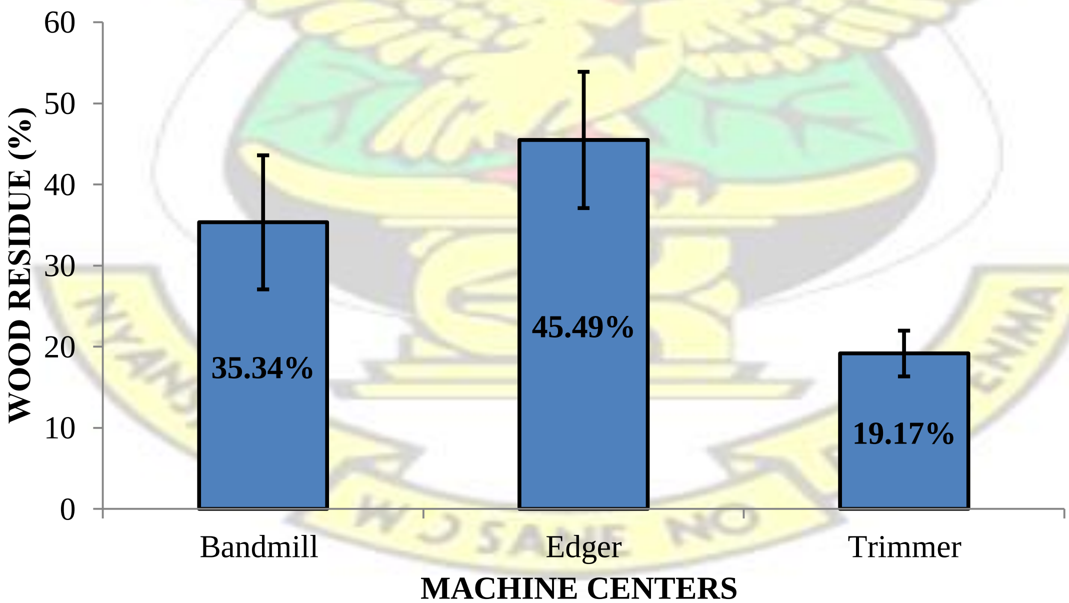
Error bars at 95% CL

Figure 3.5 Residues generated from *Entandrophragma angolense* as a percentage of total residue volume



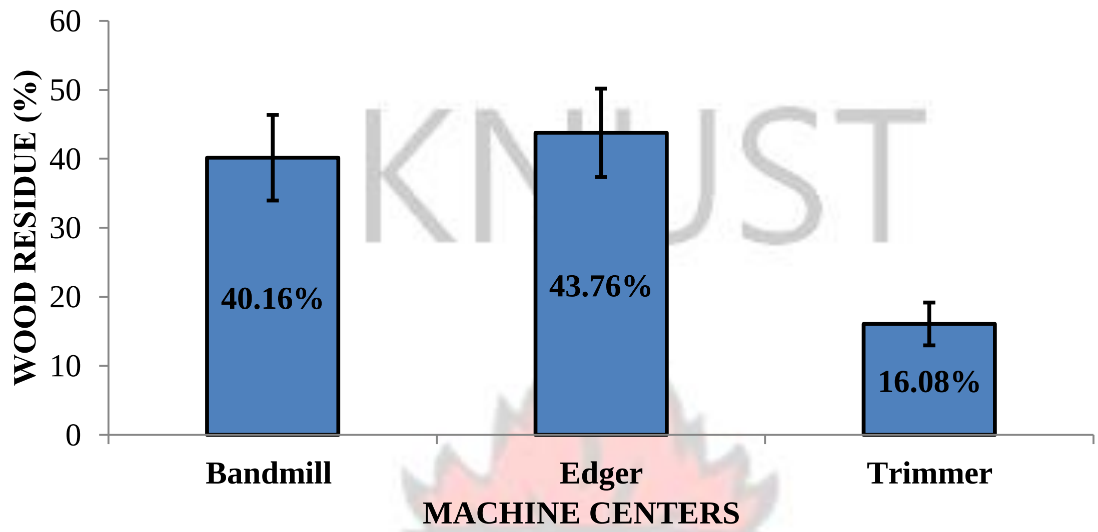
Error bars at 95% CL

Figure 3.6 Residues generated from Company A as a percentage of total residue volume



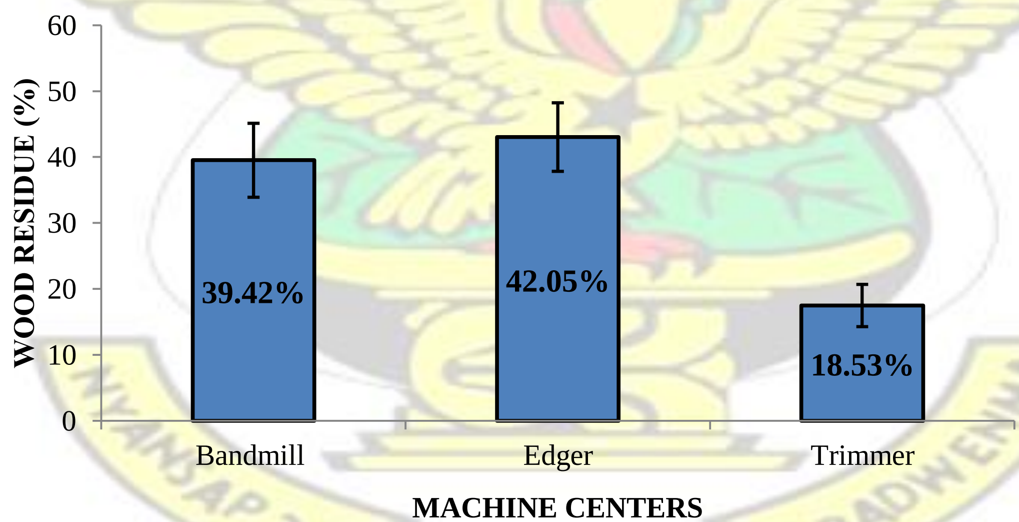
Error bars at 95% Cl

Figure 3.7 Residues generated from Company B as a percentage of total residue volume



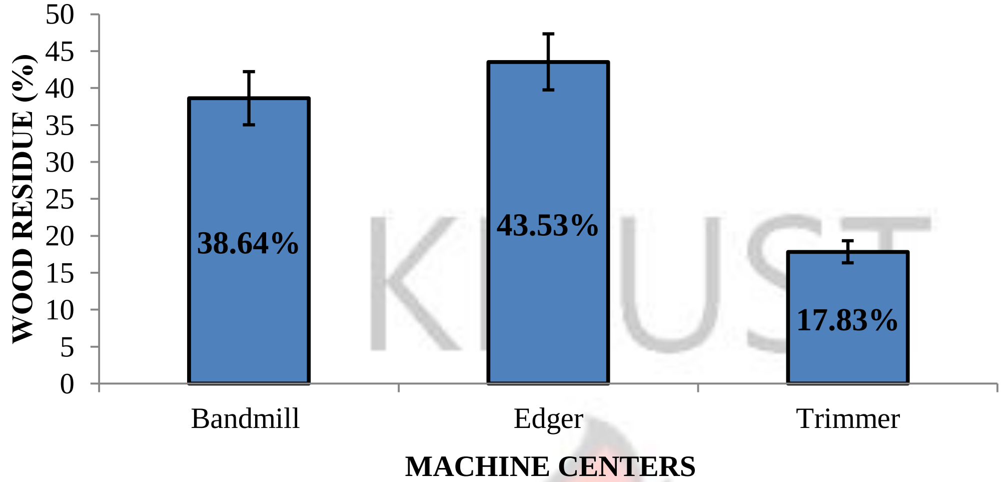
Error bars at 95% CL

Figure 3.8 Residues generated from Company C as a percentage of total residue volume



Error Bars at 95% CL

Figure 3.9 Residues generated from Company D as a percentage of total residue volume



Error Bars at 95% CL

Figure 3.10 Residues generated from the machine centres as a percentage of total residue volume for all the companies

Figure 3.6 – Figure 3.13 show that the edger had the highest residue generated as a percentage of total residue volume which ranged between 39.88% and 46.78%, followed by the bandmill which also ranged between 33.51% and 43.72%. The trimmer produced the lowest residue ranging between 14.80% and 19.71% of the total residue percentage. However, there was a deviation in Figure 3.8 (*C. gabunensis*) which had a higher percentage residue in bandmill (43.72%) as against the edger (39.88%). Figure 3.14, a summary of the production processes showed that the average percentage residue that was produced as a percentage of total residue volume at the bandmill was 38.64%; that for the edger was 43.53%; and that for the trimmer was 17.83%.

The volumes of residue generated at the various machine centres are tabulated in Table 3.19, with details at Appendices Ia - Ih. It was observed that the four study mills had the same kerf widths for the bandmills (3.40mm), the edgers (6.50mm) and the trimmers (6.30mm).

Table 3.19 Wood Residue generated at the various Machine Centres (coarse and sawdust) in percentage of their input volumes.

Company	Bandmill	Edger	Trimmer
A	**26.11**	**37.87**	**25.23**
B	**21.94**	**36.18**	**23.89**
C	**24.01**	**34.43**	**19.29**
D	**23.39**	**32.56**	**21.28**
Total	**95.45**	**141.04**	**89.69**
Mean	**23.86**	**35.26**	**22.42**

Table 3.19 gives a general trend of the edger (35.26%) having the highest percentage residue, followed by the bandmill (23.86%) and then the trimmer (22.42%).

Analysis of Variance (ANOVA) test to determine if there were any significant differences between the machine centres was conducted. The **descriptive table** (Appendix II) provides some very useful descriptive statistics, including the mean, standard deviation and 95% confidence intervals for the dependent variable (Volume of waste of each species: coarse residue - CR and sawdust residue - SR) for each separate machine level (Bandmill, Edger and Trimmer), as well as when all the machine levels are combined (Total). Considering the coarse residue for Wawa for instance, the machine level (Edger) generated the largest mean of 0.429 volume of waste with a corresponding 95% confidence interval of between 0.3135 and 0.5445. On the issue of sawdust residue for Wawa, the situation was however different, as the machine level, „Bandmill", generated the largest mean volume of waste (0.12207) with a corresponding 95% confidence interval of between 0.09176 and 0.15237.

The **ANOVA** table, Table 3.20 shows the output of the ANOVA analysis for all the species (*Cylicodiscus gabunensis*, *Entandrophragma angolense*, *Pterygota macrocarpa* and *Triplochiton scleroxylon*) and, whether there were statistically significant differences between machine level means.

Table 3.20 The Results of the ANOVA for the production process

ANOVA						
		Sum of Squares	d.f.	Mean Square	F	Sig.
Triplochiton scleroxylon coarse residue	Between Groups	1.129	2	0.565	12.681	0.000
	Within Groups	3.873	87	0.045		
	Total	5.002	89			
Triplochiton scleroxylon sawdust residue	Between Groups	0.249	2	0.124	55.73	0.000
	Within Groups	0.194	87	0.002		
	Total	0.443	89			
Cylicodiscus gabunensis coarse residue	Between Groups	1.119	2	0.559	40.008	0.000
	Within Groups	1.216	87	0.014		
	Total	2.335	89			
Cylicodiscus gabunensis sawdust residue	Between Groups	0.203	2	0.102	79.657	0.000
	Within Groups	0.111	87	0.001		
	Total	0.314	89			

Pterygota macrocarpa coarse residue	Between Groups	0.299	2	0.15	4.852	0.010
	Within Groups	2.682	87	0.031		
	Total	2.981	89			
Pterygota macrocarpa sawdust residue	Between Groups	0.382	2	0.191	48.852	0.000
	Within Groups	0.34	87	0.004		
	Total	0.722	89			
Entandrophragma angolense coarse residue	Between Groups	1.292	2	0.646	47.448	0.000
	Within Groups	1.185	87	0.014		
	Total	2.477	89			
Entandrophragma angolense sawdust residue	Between Groups	0.163	2	0.082	93.46	0.000
	Within Groups	0.076	87	0.001		
	Total	0.239	89			

According to Table 3.20, significance levels (*p* – values) for all the species in the table are all less than the risk value = 0.05. Therefore, there is a statistically significant difference in the mean volume of waste generated by the various machine levels. This is irrespective of whether the waste is coarse residue or sawdust. For example, *Triplochiton scleroxylon* coarse residue generated by the machine levels registered a *p* value = 0.000 which is less that the risk value = 0.05. This indicates that the mean volume of waste (i.e. the course residue) generated by the machine levels differed.

From the results so far, there are significant differences between the volumes of waste generated by the machine levels as a whole. Appendix III, which is Multiple Comparisons test **(**Tukey post-hoc test), shows which groups differed from each other. The Tukey post-hoc test revealed that the volume of coarse residue (CR) for *Triplochiton scleroxylon* was statistically significantly lower for machine level, Bandmill (*p* = 0.000) and Trimmer (p = 0.000), compared to the Edger. This means that, the Edger produced volume of waste (i.e. coarse residue) that was significantly greater than that of the other machine levels. This was clearly visible in the descriptive table. However, there were no differences between the waste generated by the machine levels, Bandmill and Trimmer (p = 0.953) for *Triplochiton scleroxylon* coarse residue.

Again, the volume of sawdust waste (SR) for *Triplochiton scleroxylon* was statistically significantly lower for machine level, Edger (p = 0.000) and Trimmer (p = 0.000), compared to the Bandmill. This means that, the Bandmill produced volume of waste (i.e. sawdust residue) that was significantly greater than that of the other machine levels. This was also visible in the descriptive table. However, there were no differences between the waste generated by the machine levels, Edger and Trimmer (p = 0.368) for *Triplochiton scleroxylon* sawdust residue. The full results are shown in Appendix III.

3.5.3 Types of Residues identified in the production process

The residues identified in the production process were:

- Sawdust: Sawdust was common along the production lines; the bandmills, edgers and trimmers. Sawdust constituted about 14.65% of the total residues (Table 3.18).
- Slabs: They were produced at the band mill. Slabs also constituted about 27.15% of the total residues (Table 3.18).
- Edgings: They formed about 40.84% of the total residues (Table 3.18).

- Trimmings: They were produced at the trimmer where length of lumber is cut to contract specifications. They form about 17.36% of the total residues (Table 3.18). The defective lumber was added to the trimmings.

3.6 Discussion

3.6.1 Lumber recovery and residue generation from the study sites

It was observed from Table 3.18 that, the average percentage lumber recovery for the logs processed was 38.08%, which ranged from 33.27 to 44.91% (Tables 3.2 to 3.17). This is in line with Noack (1995) who reported that lumber recovery ranged from 36% to 57%. Gyimah and Adu-Gyamfi (2009) after a pilot study on sawnwood conversion efficiency in selected sawmills in Ghana indicated that the mean recovery for small to large scale enterprises ranged from 28% to 64%. Nketiah *et al.*, (2001) also recorded lumber recovery of 30-45% in sawmills in Ghana.

Figure 3.14 shows that the average residue generated as a percentage of total residue volume that was produced at the edger was 43.53%; that for bandmill was 38.64% and that for the trimmer was 17.83%. Figures 3.6 to 3.13 followed the same trend except for Figure 4.8 which showed the greatest percentage residue in bandmill, followed by the edger and then the trimmer for *C. gabunensis*. This might be due to the large portion of distinct sapwood as explained by CIRAD (2009). Adams (2007) also confirmed that species characteristics, especially the percentage of sapwood, particularly if it is of a different colour, lower durability and strength compared to the heartwood, affects recovery. This might have reflected in the huge bandmill residue (43.72%) in Figure 3.8. This is because sapwood which is usually of lower quality had to be removed. The study has revealed that the edger generally generated most residues in the sawmilling process. Moreover, the residues generated at the edgers (edgings) were often more than the bandmills (slabs) which are also more than the trimmers (trimmings) of the sawmilling residues (Figure 3.14).

Table 3.18 shows that the bandmill generated a total sawdust of 17.790m^3 (7.12% of input volume), the edger generated 4.168m^3 (1.67% of input volume) and the trimmer 0.716m^3 (0.29% of input volume) from a total log input of 249.895m^3. This implies for every 249.895m^3 of log input an average of about 22.674m^3 (9.07% of input volume) generates sawdust. However about 60% of this sawdust is not utilized making the environment aesthetically unclean. According to Odoom (2004) and Ocloo and Yeboah (1980), sawdust is rarely used and creates environmental hazards besides being a fire hazard since it is usually disposed of by dumping or open burning.

3.6.1.1 Residues at the sawmills

Cooper (1994) defines a sawing pattern or cutting as a predetermined pattern for converting logs into lumber. All the mills made use of sawing around (sawing for grade) which is a sawing pattern which saws all faces around the log, turning it as needed to remove each board from the face promising the highest grade. When defects are encountered, the log is turned to its best face. Defects are concentrated in a box heart (How *et al.*, 2007 and Walton, 1974). Tables 3.4, 3.7, 3.12 and 3.15 shows that, residues generated at the various companies were in descending order as follows: Company A (65.67%) > Company B (62.09%) > Company C (59.78%) > Company D (59.33%). Tables 3.8, 3.9, 3.16 and 3.17

also showed that in comparing the various species, the residue generated was in the order *C. gabunensis* (65.88%) > *T. scleroxylon* (62.67%) > *P. macrocarpa* (62.06%) > *E. angolense* (56.76%).

C. gabunensis has its yellowish brown heartwood distinctly demarcated from its creamy white to pinkish sapwood (CIRAD, 2009). The high percentage of residue it generated might be as a result of its high percentage of sapwood (Adams, 2007) and (Brown *et al.*, 1994). The heartwood of *E. angolense* is pale redish brown with creamy white to pinkish sapwood (CIRAD, 2009). However, the sapwoods were not extremely big so this might have resulted in the comparatively lower percentage residue (Adams, 2007) and (Brown *et al.*, 1994). For *T. scleroxylon* and *P. macrocarpa,* although the sapwoods are not clearly distinguished from the heartwood (CIRAD, 2011), they still had lower recoveries since they had a lot of defects. The quality and quantity of lumber produced in the sawmill depend to a great extent on the quality of the raw material (log) that is processed (Odoom, 2004) and (Hoadlley, 1980).

3.6.1.2 Residues at the machine centres

According to Rappold (2006), sawing process involves functions by the bandmill, the edger and the trimmer. Each of these machine centres is involved in residue generation. In this study, each of the machine centres generated different quantities of residues that added up to the overall residue generated. The edger had the highest (43.53%), which ranged between 39.88% and 46.78%, followed by the bandmill (38.64%) which also ranged between 33.51% and 43.72%. The trimmer produced the lowest residue (17.83%) ranging between 14.80% and 19.71% of the total residue. This confirms the findings of Ofosu-

Asiedu *et al.* (1988) and Agyeman (1998) that edgings and slabs make up more than 55% of sawmill residue.

The edger produced volume of coarse residue that was significantly greater than that of the other machine levels, however, the volume of sawdust residue (SR) was statistically significantly lower for machine level, Edger and Trimmer, compared to the Bandmill. Thus the Bandmill produced volume of sawdust residue that was significantly greater than that of the other machine levels.

3.6.1.3 Types of residues generated

The types of residues generated were slabs (42.009m^3), edgings (63.193m^3). trimmings (26.869m^3) and sawdust (22.674m^3). With respect to the total percentage residue generated, slabs constituted 27.15%, edgings 40.84%, trimmings 17.36% and sawdust 14.65% (Table 3.18).

3.7 Conclusion

The amount of residues measured in this study showed that the sawmills converted more than 60% of their input into residues. The edger generated about 43% of all residues produced during sawmilling. The edger produced the highest volume of coarse residue; however, the volume of sawdust residue (SR) was highest at the Bandmill. The various types of wood residues identified in the production processes were sawdust; slabs; edgings; and trimmings.

3.8 Recommendation

Sawmillers should measure and keep records of the recovery of wood at each machine centre so that the exact cause of huge generation of residues could be easily noticed to enable mills adopt strategies to make improvements to reduce mill residue generation. More attention should be given to the trimmer operators to ensure reduced residue generation. Also the sawdoctoring at the trimmers and bandmills should be improved.

CHAPTER FOUR

4.0 EVALUATION OF THE EXISTING USES OF WOOD RESIDUES AND THEIR ECONOMIC VALUES

4.1 Introduction

The forest sector in Ghana is dominated by the timber industries and ranked fourth to gold, tourism and cocoa in Ghana"s economy (Ghana Forestry Commission (GFC), 2009). The timber industries accounted for 3.7% of GDP in 2009 and contributed US$240.9 million (representing 7.6%) to total export value. It is estimated that about 120,000 people are formally employed by the forest and wildlife sector, and it serves as a source of livelihood for about two million people (Bank of Ghana, 2004). Currently, the timber industry faces acute raw material shortages as a result of exploitation above the Annual Allowable Cut (AAC) of 1.5 million m^3 to adequately supply their mills (GFC, 2006; Bank of Ghana, 2004).

Technical efficiency, which is the efficiency of converting inputs to outputs, directly affects cost and consequently affects profits and capital investment. The aim of any sawmill is to maximize profit through the combined effect of obtaining the highest yield of acceptable quality lumber produced and increased sales. Sawmilling generates residues even when the most technologically advanced and efficient conversion methods and techniques are used (Ofosu-Asiedu *et al.*, 1988; FAC, 1972). The enormous wastage of wood in sawmills constitute a serious drain on the forest resource base and poses a threat to sustainability (Odoom, 2004). In many occasions, the waste produced even adds up to the total production cost through the cost incurred by transporting the waste to the dumping site (Agyeman, 1998; Ocloo and Yeboah, 1980).

The fast diminishing quantity of merchantable timber has made the idea of efficient timber use an attractive approach of helping to reduce waste that has hitherto characterized wood processing in Ghana (Raw Material Research Development Council, 1991). Judging from the amount of wood residues generated in relation to the input log volume, which is between 30-45% of the log input (Nketiah *et al.*, 2001), or even 50 and 80% of input volume (Noack, 1995), tremendous benefit could be obtained if given the needed attention such as further processing or recycling. The study therefore sought to express residue generated in quantitative terms to establish the economic significance and enable mill managers to know how much is actually being lost and its associated effect on the sawmills.

4.2 Objectives

The specific objectives of the study were as follows:

- To find out the uses of wood residues at the study sawmills.

- To assess the economics of sawmilling and wood residue utilization.

4.3 Materials and Methods

4.3.1 Description of study areas

The study was carried out at four sawmills. Details of the sawmills are presented under Chapter 3.3.1

4.3.2 Data collection processes

The processes of data collection involved the use of questionnaires, personal interviews, observations and field work.

4.3.2.1 Questionnaires

Data was collected through structured questionnaires which were administered to Production Managers, Marketing Managers and Finance Officers in the various sawmills that were studied. The questionnaires were designed to determine the cost of raw material, wages and salary, overhead cost, maintenance cost and how wood residues were managed (Appendices IVa, IVb and IVc).

4.3.2.2 Personal Interviews

Production Managers, Marketing Managers, Personnel Managers, Accountants, Graders, Factory Floor Members and Wood Residue users were interviewed on the production processes, disposal of wood residues and cost of wood residues.

4.3.2.3 Observations

The sawmill production processes were observed from the bandmill to the trimmer and special attention was given to the types of wood residues that were produced and how they were used or disposed off.

4.3.3. Production Cost and Benefit

The production cost involves cost incurred on items such as raw material, electricity, maintenance, wages and salary, overheads, transportation (logs from the forest to the sawmill), sawdust carting and others that made the manufacture of lumber and residue possible (Figure 4.1). An overhead is a cost or expense (such as for administration, insurance, rent, and utility charges) that relates to an operation or the company as a whole, does not become an integral part of a good or service (unlike raw material or direct labor), and cannot be applied or traced to any specific unit of output. Overheads are indirect costs www.businessdictionary.com/definition/overhead.html#ixzz3p7ll80Vs. Questionnaires and interviews were used to gather information about the production cost and benefit. Prices of logs and lumber were obtained from the TIDD Office in Kumasi.

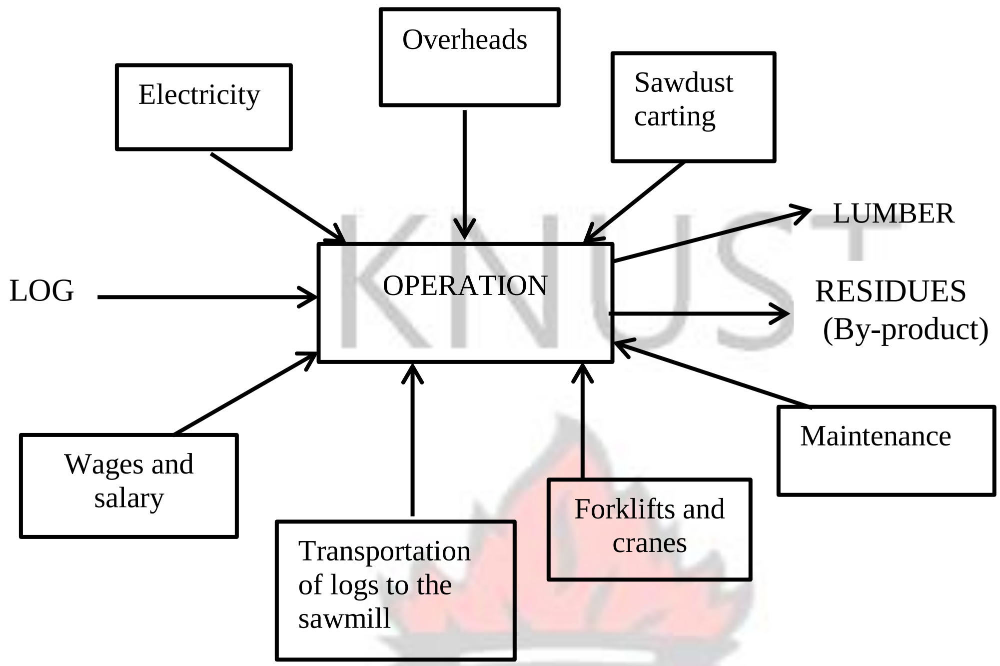


Figure 4.1 Materials and Operational Flow Diagram Source: Field Survey, 2012

N.B. Profit (Benefit) = (Lumber Price +Residue Price) – Production Cost

According to Agyeman (1998), money spent on processing lumber and residue becomes the basis for determining the unit value for residue generated. Thus, money spent per unit volume of wood (production cost) has been assumed to be the inherent value of all wood coming out of the manufacturing process either as the main product or the by-product that must be recovered. He used the Hypothetical equation;

$$y = ax$$

Where y = cost of production (in a month)

x = volume of logs processed (in a month)

a = cost per unit volume (for a month)

Thus the operational cost per unit volume has been used as the standard value for residue generated in the sawmilling operation.

4.4 Results

4.4.1 Residue utilization at the various sawmills

Table 4.1, a summary of results from the questionnaires, interviews and observations at the four sawmills showed that out of the 61.92% residue, an average of about 5% of the slabs, 5% of the edgings and 20% of the trimmings were recovered through downstream processing into items such as tongue and groove (T&G), skirting strips, quarter battens, pipe strips and wooden tiles (parquet or floorings). Thus, the residues reduced from 61.92% to about 57.67% of log volume. Recovery therefore, increased from **38.08%** to **42.33%.** Thus coarse residues decreased from 52.85% to 48.60% and sawdust increased from 9.07% to about **10.09%** of input volume (Table 3.18). About 40% of the sawdust, 75% of the trimmings, 20% of the slabs and 90% of the edgings went to the sawmill furnace to support heat generation. 60% of the sawdust was discarded at a dumping site outside the mills. 75% of the slabs were sold to bakers, charcoal manufacturers and small scale woodworkers.

Table 4.1 Wood residue utilization at the various sawmills

Type of residue	Volume (m^3)	Recovered (%)	Recovered (m^3)	To furnace (%)	Sold (%)	Discarded (%)
Slabs	42.009	5.00	2.100	20.00	75.00	0.00
Edgings	63.193	5.00	3.160	90.00	4.00	1.00
Trimmings	26.869	20.00	5.374	75.00	4.00	1.00

Sawdust	22.674	0.00	0.000	40.00	0.00	60.00

Source: Field Survey, 2012

Table 4.1 shows that the total volume recovered through further processing was given by the sum recovered from the slabs, edgings and trimmings, given by:

Volume from further Processing (Recovered) = (2.100 + 3.160 +5.374) m^3 =10.634m^3

This was used for items such as finger joints, tongue and rove (T&G), wooden tiles and pipe strips.

Residue recovered (%) = $\frac{10.634}{249.895} \times 100 =$ **4.26%** of Input Volume

From Table 3.18, the volume of the original output was 95.150m^3 and original input was 249.895m^3. The new final recovery was given by:

$$\text{Final Recovery (\%)} = \frac{\text{(Original Volume Output + Volume from further Processing)}}{\text{Original Volume Input}} \times 100$$

$$= \frac{95.150 + 10.634}{249.895} \times 100 \quad = \frac{105.784}{249.895} \times 100 = \mathbf{42.33\%}$$

New Residue (%) = 100 – 42.33 = **57.67%**

From Table 4.1, it was deduced that about 27% (35.110m^3) of the coarse residue was sold.

4.4.2 Economic assessment of sawmilling and wood residues

The profit generated by a sawmill is simply estimated by the difference between revenues and expenditure. The cost associated with the production of lumber and residues were assessed in Companies A and D, (they gave the entire details on their monitory issues to enhance a successful assessment; however similar machines and processes were in the other industries so these gave an idea of what happened in the other industries). This formed the basis for estimating the price per unit volume of lumber and the shadow price for a unit volume of residue. This was to assess how much revenue went into production of total wood residue and also how much revenue could be made in case wood residue was used and/or sold instead of dumping it in landfills or discarded by burning.

The cost items constituting the production at Companies A and D were raw material, machine maintenance, electricity, wages and salaries of workers, forklift fuel consumption, transportation, sawdust carting to dumping site and general overheads. It should be noted that the sawmills had their own means of transport.

4.4.2.1 Production cost associated with Company A

Estimates for cost associated with Company A‟s production processes were studied. Table 4.2 Cost items of production per month at Company A

Inputs	**Costs (GH¢)**
Raw Material	135,498.00
Machine maintenance	3,900.00
Electricity	54,957.20
Wages and Salaries of workers	7,766.12

Forklift fuel consumption	1,100.00
Transportation of logs to sawmill	19,000.00
Sawdust carting to dumping site	480.00
General overheads	500.00
Total	**223,201.32**

Source: Field Survey, 2012

Table 4.2 gives the cost incurred for a month (GH¢ 223,201.32) in the production of 1,100.000 m^3 of bolts. However 69.603 m^3 of bolts were processed in the study.

According to Table 4.3, for Company A, about GH¢ 14,121.07 was spent on processing 69.603m^3 of bolts into lumber and residue during the study period. GH¢ 9,275.21 out of this was spent to produce 45.709m^3 of residue. The cost per unit volume of residue was GH¢ 202.91. This was equivalent to about 101 US Dollars (2012).

Table 4.3 Estimated Cost of Production at Company A (Estimates in Ghana Cedis)

ITEMS	Unit cost per m^3	Cost/ Month for am^3	Cost for bm^3 of bolts	Cost for cm^3 of residues
Raw Material	123.18	135,498.00	8,573.69	5,630.43
Machine maintenance	3.55	3,900.00	245.06	162.67
Electricity	49.96	54,957.20	3,477.37	2,283.62
Wages &Salaries of workers	7.06	7,766.12	491.40	322.71
Forklift fuel consumption	1.00	1,100.00	69.60	45.71
Transportation of logs to sawmill	17.27	19,000.00	1,202.00	789.39
Sawdust Carting	0.44	480.00	30.63	20.11
General overheads	0.45	500.00	31.32	20.57
Total	**202.91**	**223,201.32**	**14,121.07**	**9,275.21**

(Source: Field Survey, 2012)
Where am^3 = Average volume of bolts per month (1,100.000m^3/month)
bm^3 = Volume of bolts during study (69.603m^3) Ten days for one shift.
cm^3 = Volume of residue during study (45.709m^3) (Appendices V and VI.).

4.4.2.2 Revenue obtained from sale of residues at Company A

Sawdust which formed about 7.050 m^3 at Company A was not sold. About 40% was used in the furnace to support energy generation for production process, while the remaining was sent to a dumping site for burning. About 10.438m^3 (27%) of coarse residue was sold by Company A at GH¢ 100 per tractor load. An average tractor load was 3.835 m^3. This means a cubic metre of residue was sold for $\left(\frac{100}{3.835}\right)$ = GH¢ 26.08. Therefore, Company A received (26.08×10.438) = GH¢ 272.22 from sale of coarse residue generated from 69.603m^3 of bolt volume input. For a monthly average of 1,100.000m^3, Company A would reap (26.08× 164.961) = GH¢ 4,302.18 from sale of coarse residue per month.

Table 4.4 shows a negative revenue (or loss in revenue) in the production of residue. For each cubic metre of residue generated, Company A lost GH¢ 176.83. During the study, for bolt input of 69.603m^3, Company A lost GH¢ 8,082.72 to residue. It was therefore estimated that for a monthly input of 1,100.00m^3, Company A was expected to lose GH¢ 127,736.68, even after sale of 164.961m^3 of residue.

Table 4.4 Cash flow for residue generation at Company A (Estimates in Ghana Cedis).

ITEMS	Unit Estimate Per m^3	65.67% of 69.603m^3 (45.709m^3)	65.67% of 1,100.000m^3 (722.370m^3) per month

REVENUES			
Sale of coarse residue	26.08	1,192.09	18,839.41
COST (expenditure)		5,630.43	
Raw Material	123.18		88,981.54
Machine maintenance	3.55	162.27	2,564.41
Electricity	49.96	2,283.62	36,089.60
Wages and Salaries of workers	7.06	322.71	5,099.93
Forklift fuel consumption	1.00	45.71	722.37
Transportation of logs to sawmill	17.27	789.39	12,475.33
Sawdust carting	0.44	20.11	317.84
General overheads	0.45	20.57	325.07
Subtotal	**202.91**	**9,274.81**	**146,576.09**
NET REVENUE	**-176.83***	**-8,082.72***	**-127,736.68***

(Source: Field Survey, 2012)

N.B. NET REVENUE = REVENUES – COST (expenditure)

* Negative Revenue Means Loss

4.4.2.3 Production cost associated with Company D

Estimates for cost associated with Company D"s production processes were studied.

Table 4.5 Cost items of production per month at Company D

Inputs	Costs (GH¢)
Raw Material	153,358.50
Machine maintenance	3,000.00
Electricity	35,600.00
Wages and Salaries of workers	6,000.00
Forklift fuel consumption	900.00
Transportation of logs to sawmill	15,680.00
Sawdust carting	310.00

General overheads	370.00
Total	**215,218.50**

Source: Field Survey, 2012

Table 4.5 gives the cost incurred for a month (GH¢ 215,218.50) in the production of 950.00 m^3 of bolts in Company D. However, 51.439 m^3 of bolts were processed in the study.

Table 4.6 shows that, at Company D, about GH¢11,653.89 was spent on processing 51.439m^3 of bolts into lumber and residue during the study period. GH¢ 6,913.39 out of this was spent to produce 30.516m^3 of residue. The cost per unit volume of residue was GH¢ 226.55. This was equivalent to about 113 US Dollars (March, 2012).

Table 4.6 Estimated Cost of production at Company D (Estimates in Ghana Cedis)

Items	**Unit Cost per m^3**	**Cost /Month for dm^3 of bolts**	**Cost for em^3 of bolts**	**Cost for fm^3 of residues**
Raw Material	161.43	153,358.50	8,303.93	4,926.20
Machine maintenance	3.16	3,000.00	162.55	96.43
Electricity	37.47	35,600.00	1,927.42	1,143.43
Wages & Salaries of workers	6.32	6,000.00	325.09	192.86
Forklift fuel consumption	0.95	900.00	48.87	28.99
Transportation of logs to sawmill	16.50	15,680.00	849.00	503.51
Sawdust carting	0.33	310.00	16.97	10.07
General overheads	0.39	370.00	20.06	11.90

TOTAL	**226.55**	**215,218.50**	**11,653.89**	**6,913.39**

(Source: Field Survey, 2012)

Where dm^3 = Average volume of bolts per month ($950.000m^3$/month)
em^3 = Volume of bolts during study ($51.439m^3$) fm^3 = Volume of residue during study ($30.516m^3$) (Appendices V and VI).

4.4.2.4 Revenue obtained from sale of residues at Company D

Sawdust which formed about $4.744m^3$ was not sold by Companies D. About 40% was used in the furnace to support energy generation for production process and the rest sent to the dumping site for burning. $6.958m^3$ (27%) of coarse residue was sold at GH¢ 90.00 per tractor load. An average tractor load was $3.835m^3$. This means a cubic metre of residue cost ($\frac{90}{3.835}$) = GH¢ 23.47. Therefore, Company D received (23.47×6.958) = GH¢ 163.30 from sale of coarse residue generated from $51.439m^3$ of bolt volume input. For a monthly average of $950.000m^3$, Company D would reap (23.47×128.50) = GH¢ 3,015.90 from sale of coarse residues per month.

Table 4.7 Cash flow for residue generation at Company D (Estimates in Ghana Cedis).

ITEMS	Unit Estimate Per m^3	59.33% of $51.439m^3$ ($30.516m^3$)	59.33% of $950.000m^3$ ($563.635m^3$) per month
REVENUES			
Sale of coarse residue	23.47	716.21	13,228.51
COST (expenditure)			
Raw Material	161.43	4,926.20	90,987.60
Machine maintenance	3.16	96.43	1,781.09
Electricity	37.47	1,143.43	21,119.40
Wages and Salaries of workers	6.32	192.86	3, 562.17

Forklift fuel consumption	0.95	28.99	535.45
Transportation of logs to sawmill	16.50	503.51	9,299.98
Sawdust carting	0.33	10.07	186.00
General overheads	0.39	11.90	219.82
Subtotal	**226.55**	**6,913.39**	**127,691.51**
NET REVENUE	**-203.08***	**-6,197.18***	**-114,463.00***

(Source: Field Survey, 2012)
N.B. NET REVENUE = REVENUES – COST (expenditure)
* Negative Revenue Means Loss

According to Table 4.7 there was a negative revenue (or loss in revenue) in the production of residue. For each cubic metre of residue generated, Company D lost GH¢203.08. During the study, for bolt input of 51.439m^3, Company D lost GH¢ 6,197.18 to residue. It is therefore estimated that for a monthly input of 950.000m^3, Company D was expected to lose GH¢ 114,463.00, even after sale of 128.500m^3 of residue.

4.4.2.5 Estimated cost of production at Companies A and D compared

All the mills employed the same sawing method (sawing around also known as sawing for grade) (Plate 2.4). Table 4.8 compares the production cost of Companies A and D.

Table 4.8 Estimated cost of production at Companies A and D (Estimates in Ghana Cedis)

COST ITEMS per m^3	COMPANY A		COMPANY D	
	Unit Cost per m^3	Cost during study per m^3	Unit Cost per m^3	Cost during study per m^3
Raw Material	123.18	8,573.69	161.43	8,303.93
Machine maintenance	3.55	245.06	3.16	162.55

Electricity	49.96	3,477.37	37.47	1,927.42
Wages &Salaries of workers	7.06	491.40	6.32	325.09
Forklift fuel consumption	1.00	69.60	0.95	48.87
Transportation of logs to sawmill	17.27	1,202.00	16.50	849.00
Sawdust Carting	0.44	30.63	0.33	16.97
General overheads	0.45	31.32	0.39	20.06
Total	**202.91**	**14,121.07**	**226.55**	**11,653.89**

(Source: Field Survey, 2012)

4.5. Discussion

4.5.1. Residue utilization at the various sawmills

According to Brink (2003), the idea that wood can be recycled or reused and not hauled straight to the landfills, makes sense. Table 4.1 shows that, apart from the sawdust which had about 60% being discarded, only about 2% of the coarse residue was discarded. This was confirmed by Bogart (2004) who stated that the least favored option for residue is sending the material to a landfill. Dost (1966) defined wood residue as the remnant of the original raw material after the economic value has been removed. This means the 4.26% of input volume that was recovered from downstream processing has gained a kind of economic value which will cause the net profit of the sawmill to increase. Using wood residue locally creates jobs and strengthens local economy.

4.5.2. Economic assessment of sawmilling and wood residues

According to Noack (1995) lumber recovery ranged from 36% to 57%. Gyimah and AduGyamfi (2009) reported a mean recovery for small to large scale enterprises as 28% to

64%. Nketiah *et al.*, (2001) also recorded lumber recovery of 30-45% in sawmills in Ghana. Thus on the average, quantities of residues generated by Ghanaian sawmills exceed that of lumber. In this study, an average of 61.92% of input bolt volume was turned into residue in the four sawmills. Dost (1966) defined wood residue as the remnant of the original raw material after the economic value has been removed. Hence, residue may be regarded as negative product of wood processing, thus reducing the profit margin. A greater proportion of residues were not properly utilized and not much attempt was made to salvage those residues from going down as waste, for other production purposes.

The principal objective of a sawmill is to make maximum profit from its input, which is the difference between revenues and expenses. Thus benefits accrued from production should exceed production cost. According to Gregerson and Contreras, (1992) a project must be able to have benefits from production which exceeds cost of production. However, according to Appiah, (1983) since sawmill residue is above 50% of the input volume, its economic utilization is important. This helps to reduce the pressure on the forest through reduced harvesting rate of fresh logs. According to Bogart (2004) and Brink (2003) the least favored option for wood residue is sending material to a landfill, which further adds more cost to production cost. The cost of production and the volume of wood processed varied in the two companies. The cost benefit analysis at Companies
A and D were studied. Cost-benefit analysis is the examination of a decision in terms of its consequences or costs and benefits. Cost-benefit analysis is a framework to assess the merits of an activity (project, policy) from the perspective of society (as opposed to a single individual). It involves:

- measuring the gains and losses (benefits and costs) from an activity to the community using money as the measuring rod; and
- aggregating those values of gains and losses and expressing them as net community
- gains or losses (Holland, 2012).

4.5.2.1. Cost Benefit Analysis of production at Company A

Company A spent about GH¢ 14,121.07 on processing 69.603m^3 of bolts into lumber and residue during the study period. GH¢ 9,275.21 out of this was spent to produce 45.709m^3 of residue. Thus about 65.67% of the total amount was spent as cost of generating residues. The cost per unit volume of residue was GH¢ 202.91 (Table 4.3).

Profit (Benefit) = (Lumber Price + Residue Price) – Production Cost

During the study, coarse residues sold earned the company GH¢ 272.22, and cost of production of 69.603m^3 of bolts into lumber and residue was GH¢ 14,121.07.

Money earned from lumber during the study = Money earned from (Wawa + Denya)

= GH¢ (16.263 × 728.51) + (7.631 × 1,138.30)

= GH¢ 11,847.76 + 8,686.37 = GH¢ 20,534.13 (Appendix VI, Table 3.2 and Table 3.3).

Therefore Profit = GH¢ (20,534.13 + 272.22) – 14,121.07

= GH¢ 20,806.35 – 14,121.07 = GH¢ 6,685.28

Thus if GH¢ 6,685.28 was accrued on 69.603m^3 during the study period, then for a month of 1,100.000m^3 of logs, Company A will be able to make a profit of about GH¢ 105,653.61. In the case of a better production process, if the residues were to be used for items like finger-joints or even for contracts with smaller dimensions (e.g. floorings), a 20% output (0.2 × 45.709m^3 = 9.142m^3) could earn Company A an extra

(20,534.13 × $\frac{9.142}{23.884}$) = GH¢7,859.78 during the study period and about (7,856.49 × $\frac{1,100.000}{69.603}$) = GH¢ 124,163.31 within one month. This shows that it is not economically wise for Company A to generate so much waste.

4.5.2.2 Cost Benefit Analysis of production at Company D

Company D spent about GH¢11,653.89 on processing 51.439m^3 of bolts into lumber and residue during the study period. GH¢ 6,913.39 out of this was spent to produce 30.516m^3 of residue. Thus about 59.32% of the amount was spent as cost of generating residues. The cost per unit volume of residue is GH¢ 226.55 (Table 4.6).

Profit (Benefit) = (Lumber Price +Residue Price) – Production Cost

During the study, coarse residues sold earned the company GH¢ 163.30, and cost of production of 51.439m^3 of bolts into lumber and residue was GH¢ 11,653.89.

Money earned from lumber during the study = Money earned from (Koto + Edinam)

= GH¢ (11.451 ×1,092.77) + (9.472 ×1,115.53)

= GH¢ 12,513.31 + 10,566.30 = GH¢ 23,079.61

(Appendix VI, Table 3.13 and Table 3.14).

Therefore Profit = GH¢ (23,079.61 + 163.30) – 11,653.89

= GH¢ 23,242.91 – 11,653.89 = GH¢ 11,589.02

Thus if GH¢ 11,589.02 was accrued on 51.439m^3 during the study period, then for a month of 950.000m^3 of bolts, Company D will be able to make a profit of about GH¢ 214,031.55. In the case of a better production process, if the residues were to be used for items like finger-joints or even for contracts with smaller dimensions, a 20% output (0.2 × 30.516m^3 = 6.103m^3) could earn Company D an extra (23,079.61 ×

$\frac{6.103}{20.923}$) = GH¢ 6,732.06 during the study period and about (6,732.06 × $\frac{950.000}{51.439}$) = GH¢ 124,330.90 within one month. This shows that it is not economically wise for Company D to generate a lot of waste. According to Agyeman (1998), money spent on processing lumber and residue becomes the basis for determining the unit value for residue generated. Thus, money spent per unit volume of wood (production cost) has been assumed to be the inherent value of all wood coming out of the manufacturing process either as the main product or the by-product.

4.5.2.3 Comparing Cost Analysis of Companies A and D

Company A sawed more bolts (69.603m^3) during the study period than Company D (51.439m^3), however, Company A had a lower recovery (34.33%) than Company D (40.67%) (Tables 3.4 and 3.15). This means Company A was less efficient in recovering maximum volume lumber from its bolt input. Low recovery results in increased cost per unit output. Due to the differences in input volumes, the two companies can only be compared based on unit cost (cost per unit volume). Table 4.8 shows that, apart from cost of raw material (due to different species used), all other cost items per unit volume were higher for company A as against Company D. In effect, a lower rate of recovery of logs increases the cost per unit volume of output. This is in line with Stone (1997) who worked on timber industries in Brazil and stated that low recovery results in increased cost per unit volume of output.

Considering the two companies, Table 4.8 showed that the cost of raw materials ranked highest during production. This confirms work done by Cooper, (1994) which states that logs may account for between 70 to 90% of all costs and Rappold (2006) who demonstrated that raw material costs account for more than half of the manufacturing costs in a hardwood sawmill environment. In this study, the cost of raw material was followed by Electricity, Transportation of logs to the sawmill and Labour in decreasing order. Rappold (2006) reported that labour was usually the second largest item except in high mechanized mills. Due to high levels of electricity and fuel prices, these charges were higher than labour. General overheads, sawdust carting, forklift fuel consumption and machine maintenance formed small part of costs in the sawmills.

4.6 Conclusion

Although residues are inevitable during sawmilling, the study has revealed that residues generated has no economic benefit to the study sawmills as long as judicious and optimum economic uses are not found for them. The lesser the quantities of residues generated, the better the sawmill profitability, hence a better sustainable forest management. Wood residues have negative effect on sawmill profitability. To combat decrease in rawmaterial availability, sawmills need to improve their sawn wood recovery and add value to the residues to reduce the residues to the rarest minimum. The cost per unit volume of residue generated was between GH¢ 226.55 and GH¢ 202.91 (between $114 and $123 in 2012). In comparing Companies A and D, it was realized that low recovery results in increased cost per unit output. It was also revealed that the use of coarse wood residues generated in sawmilling as fuel to the furnace was not economically efficient and was negative to sawmill productivity.

4.7 Recommendation

One area for further research is to evaluate the economic performance of companies in the value-added product sectors such as the use of wood residue for kitchen cabinet, doors, small toys, wooden ladles and particle boards.

CHAPTER FIVE

5.0 THE DECOMPOSITION TREND OF WOOD RESIDUES

5.1 Introduction

Wood, an important multipurpose natural resource has lots of uses to which it is put to meet human needs (Kramer, 2006). Wood is an organic, renewable material which offers the benefit of carbon sequestration i.e. growing trees extract atmospheric carbon dioxide (CO

$_2$) which through the process of photosynthesis is converted into carbohydrate to support structural growth. Growing forests thus have the potential to act as a mechanism for countering the increasing global concentration of atmospheric CO_2, which has implications for climate change (TRADA, 2005).

Prominent among factors limiting crop production in Ghana is the low level of fertilizer use. This is as a result of increasing fertilizer prices. Naturally, in tropical ecologies, crops obtain most of their nutrients from decomposing organic residues (Tetteh, 2004). With the inability of most resource-poor farmers to afford mineral fertilizers, the use of plant residue (e.g. sawdust) as source of nutrients is becoming increasingly important (Thonnissen *et al*., 2000). However, there is not much information on their quality and decomposition rate for proper management. According to Quigley (1998), decomposition refers to the natural breakdown of complex organic compounds into simpler substances. Decay occurs in dead plant and animal tissue and the substances released such as carbon dioxide, ammonia and methane are absorbed by green plants for nutrition, beginning a new food chain. Without decay, the essential building blocks of life would remain locked inside the dead tissue. According to Abugre (2011), decomposition is an important part of all life cycles both in the terrestrial and aquatic environment since it acts as a way for recycling the nutrients back into the soil. As the organic materials decompose, the nutrients are released back to the soil where they help to feed vegetation in the surrounding area. According to Sanchez and Miller (1986), the C/N and lignin/N ratios can estimate the ease or otherwise of the decomposition of an organic material. The length of time it takes wood residue to decompose determines when it ceases to be a fire hazard. Generally, different wood species under the same conditions decompose at different rates, therefore the need to investigate into the decomposition rates.

5.2 Objectives

The specific objectives of the study were as follows:

- To determine wood residue water holding capacity
- To find out the quality of the sawdust
- To determine the rate of decomposition of buried and surface applied sawdust

5.3 Materials and Methods

Samples (sawdust) of each specific species were collected from the production lines. They were clean of other species. This was ensured by cleaning the entire production lines thoroughly before the production process. A clean big car duster was spread at where sawdust was produced for collection. The samples were transferred into big plastic Ziploc bags, secured, labeled and transported to the Council for Scientific and Industrial Research (CSIR) - Soil Research Institute of Ghana, Kwadaso, where field experiment and laboratory analysis were carried out. Uniform conditions were maintained for all the samples.

Council for Scientific and Industrial Research (CSIR) - Soil Research Institute of Ghana is about 8 km away from the city centre and at the South-Western part of Kumasi (Tetteh, 2004). The mean annual precipitation is about 1,500mm. Temperatures are generally high and uniform throughout the year. The mean monthly temperatures range between 24 – 28^{o}C. Relative humidity is generally high in the mornings being about 90% at 0600 hours and falling between 60% and 70% in the afternoon at 1500 hours (Tetteh, 2004). The experiments were carried out on soils classified as Ferric Acrisol (Adu, 1992).

5.3.1. Laboratory Test

5.3.1.1. Wood Residue Water Holding Capacity

Ten grams oven-dried samples of each species of the wood residues (sawdust) were equilibrated with water (200ml) in separate beakers (48 beakers) in the laboratory (Plate 5.1). Three sets of samples of each species were removed from the set up after 1, 4, 8 and 12 hours of immersion. Gravitational water was allowed to drain out of the wet samples using white polyester cloth cut into sections (in the form of handkerchiefs i.e. 20cm × 20cm) (Plate 5.2), after which the mass of the residues were taken. The difference between the wet samples (final mass) and the dry sample (initial mass) expressed as a percentage of the initial mass represented the water holding capacity. This was in line with work on some crop residues in (Tetteh, 2004).

Plate 5.1 Set up for water holding capacity

Plate 5.2 Draining of gravitational water from samples

5.3.1.2. Wood Residue Characterization

The quality of organic residues is expressed in their nutrient content; carbon/nitrogen and lignin/nitrogen ratios (Tetteh, 2004). Wood residues (sawdust) of *C. gabunensis*, *E. angolense*, *T. scleroxylon* and *P. macrocarpa* were collected from the selected sawmills. They were oven dried in a laboratory oven at 70^{o}C and milled in a Wiley stainless steel mill to pass through a 2mm sieve and stored in air-tight containers at room temperature for laboratory chemical analysis (Nelson and Sommers, 1982). Total nitrogen, phosphorus, potassium, calcium, magnesium, carbon, and lignin content were determined and used to assess the quality of the wood residues as described in Tetteh (2004). Carbon was determined by LECO carbon analyzer. Total Nitrogen by the Kjeldahl method while Ca and Mg were estimated using the EDTA titration method. Potassium was estimated using the atomic absorption spectrophotometer.

5.3.2. Field Experiment

Decomposition of sawdust of the four selected species was determined over a 12 week period between April and July 2012 at the Council for Scientific and Industrial Research (CSIR) - Soil Research Institute, Kwadaso - Kumasi. The rate of wood residue decomposition in the field was measured by the mass loss of residues with time as described by Anderson and Ingram (1993). Some wood species decompose faster than others hence the need to run decomposition test in order to effectively manage their residues.

5.3.2.1. Decomposition of Wood Residues in litter bags

The use of decomposition or litter bags makes it possible to monitor decomposition and recover the residual experimental material even after the material has undergone some decomposition and define the conditions under which the organisms operate (Anderson and Ingram, 1993). Decomposition bags (20cm × 20cm) were made from nylon mosquito nets (1.0mm mesh size). Nylon was chosen since cotton or silk material could be decomposed before the end of the experiment, making data collection impossible. A 100g oven dried samples (sawdust) each of *C. gabunensis*, *E. angolense*, *T. scleroxylon* and *P. macrocarpa* were put in litter bags. One set of samples was buried into the soil in a predetermined distance of 20cm apart, at a depth of 15cm in a relatively uniform area (leveled ground) at CSIR – Soil Research Institute from April to July 2012. The other set of samples was placed on the surface with the same arrangement as the first one in order to study the effect of placement on the rate of decomposition as shown in Plate.5,3. Three sets of plots were established to reduce experimental error. That is, there were 144 individual samples (8 samples × 6 weeks × 3 plots).

Plate 5.3 Samples on experimental plot

Samples of each wood species were taken from the field at 2, 4, 6, 8, 10 and 12 weeks. Thus six subsequent tests (mass) were taken after the initial mass for a period of twelve more weeks to determine the rate of decomposition of the test species. This experiment was carried out in the rainy season because according to Tetteh, (2004) microbial activity is minimal under dry conditions, causing little or no decomposition in the dry season.

At the end of the experiment, a hand trowel was used to harvest (remove) the samples from the experimental plots fortnightly. Contents were poured into metal trays and labeled. They were transported to the laboratory. Aluminum foil trays were weighed (W_1) using the electronic balance and the content of the metal tray transferred to the foil trays (Plate 5.4) which were weighed (W_2) (Plate 5.5).

The fresh mass of the samples (W_3) were calculated by the formula:

$$\mathbf{W_3 = W_2 - W_1}$$

Where, W_1 = Mass of empty aluminum foil tray (g)

W_2 = Mass of aluminum foil tray and sample (g)

W_3 = Mass of fresh sample (g) = 100g

Plate 5.4 Samples in Aluminum foil trays
After taking the field

Plate 5.5 Weighing of samples using an electronic balance

After taking the field fresh mass, the samples were oven dried at 70^{o}C for 48 hours and weighed until a constant mass was achieved. The dried mass was given by W_4. The percentage of the initial mass of wood residue remaining was calculated by the formula:

$$Wr = \frac{Wt}{W0} \times 100$$

Where, Wr = Wood Residue remaining (%)
Wt = Mass of wood Residue in a particular day or time (grams)
W_0 = Initial Mass of Wood Residue (grams)

5.4. Data Analysis

Data obtained on the Water Holding Capacity were subjected to Analysis of Variance (ANOVA) test to determine if there were any significant differences between the four species, then the Tukey post-hoc test was used to test the extent of the significant difference for conducting post-hoc tests on the ANOVA test. Data obtained on rate of decomposition of dumped (surface applied) and buried sawdust of the selected species was also subjected to Analysis of Variance (ANOVA) test and then the Tukey post-hoc test.

5.5. Results

5.5.1. Water holding capacity of wood residues

The percentage moisture imbibed by the wood residues (sawdust) of the selected species following equilibration with water within 12 hours is presented in Figure 5.1.

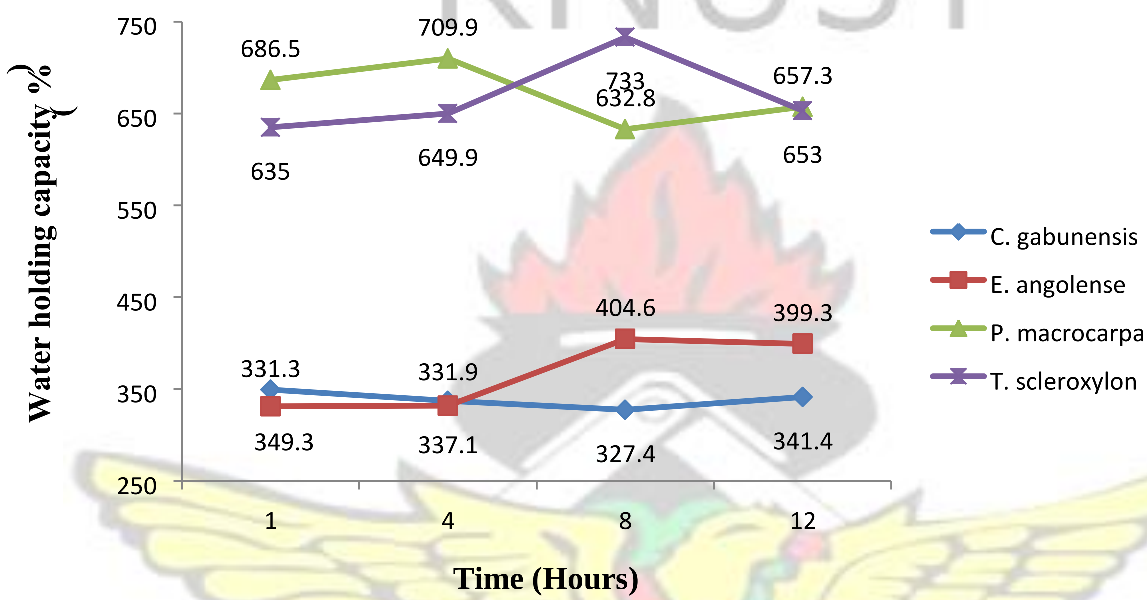


Figure 5.1 Water holding capacity of wood species

According to Figure 5.1 (details in Appendix VII), *E. angolense* and *T. scleroxylon* absorbed water gradually from the first hour to the maximum within 8 hours, after which they declined again. *P. macrocarpa* absorbed moisture to the maximum within 4hours, after which moisture content reduced and then increased slightly. *C. gabunensis* absorbed maximum moisture within the first hour and then started to decline. *T. scleroxylon* and *P. macrocarpa* had higher water holding capacities as compared to *E. angolense* and *C. gabunensis*.

Analysis of Variance (ANOVA) test to determine if there were any significant differences between the water holding capacities of the selected species was conducted. The descriptive table (Table 5.1) provides some very useful descriptive statistics, including the mean, standard deviation and 95% confidence intervals for the dependent variable (Water holding capacity) for each separate species (*C. gabunensis*, *E. angolense*, *P. macrocarpa* and *T. scleroxylon*, as well as when all species are combined (Total).

According to Table 5.1, it appears *T. scleroxylon* and *P. macrocarpa* have the same level of water holding capacity with respective indicators (767.733 ± 48.8354) and (771.633 ± 42.8592). Simialarly, it looks like *C. gabunensis* and *E. angolense* also have the same level of water holding capacity, as they registered (438.792 ± 12.4493) and (467.017 ± 49.4648) respectively.

Table 5.1 *The descriptive and Confidence Interval Table*

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
T. scleroxylon	12	767.733	48.8354	14.0976	736.705	798.762	682.2	854.3
C. gabunensis	12	438.792	12.4493	3.5938	430.882	446.702	416.1	463.5
P. macrocarpa	12	771.633	42.8592	12.3724	744.402	798.865	701.9	837.8
E. angolense	12	467.017	49.4648	14.2793	435.588	498.445	381.3	525.5

Total	48	611.294	165.2927	23.8579	563.298	659.290	381.3	854.3

Table 5.2 is the ANOVA Table of the Water holding capacity of the four species. It shows whether there is statistically significant difference between the water holding capacities of the four species. Here, the significance level is 0.000 ($p = 0.000$), which is below the risk value = 0.05. Therefore, there is a statistically significant difference among the species when it comes to their water holding capacity levels.

Table 5.2 *The ANOVA Table of the Water holding Capacity of the Species*

	Sum of Squares	d.f.	Mean Square	F	Sig.
Between Groups	1209059.649	3	403019.883	236.252	0.000
Within Groups	75059.239	44	1705.892		
Total	1284118.888	47			

From the results so far, there are significant differences between the species in terms of their capacities to hold water as a whole. According to Table 5.3, (Tukey post-hoc test Multiple Comparisons Table), there is a significant difference in water holding capacity between *T. scleroxylon* and *C. gabunensis* ($p = 0.000$), as well as between *T. scleroxylon* and Edinam ($p = 0.000$). However, there were no differences between *T. scleroxylon* and *P. macrocarpa* ($p = 0.996$). Again, there was a significant difference in water holding capacity between *P. macrocarpa* and *C. gabunensis* ($p = 0.000$), as well as between *P. macrocarpa* and *E. angolense* ($p = 0.000$). There was however no difference between *C. gabunensis* and *E. angolense* ($p = 0.349$).

Table 5.3 *Post Hoc Test: Multiple Comparisons of Species Water Holding Capacity using Tukey*

(I) Species	(J) Species	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
T. scleroxon	*C. gabunensis*	328.9417*	16.8617	.000	283.921	373.962
	P. macrocarpa	-3.9000	16.8617	.996	-48.921	41.121
	E. angolense	300.7167*	16.8617	.000	255.696	345.737
C. gabunensis	*T. scleroxylon*	-328.9417*	16.8617	.000	-373.962	-283.921
	P. macrocarpa	-332.8417*	16.8617	.000	-377.862	-287.821
	E. angolense	-28.2250	16.8617	.349	-73.246	16.796
P.macrocarpa	*T. scleroxylon*	3.9000	16.8617	.996	-41.121	48.921
	C. gabunensis	332.8417*	16.8617	.000	287.821	377.862
	E. angolense	304.6167*	16.8617	.000	259.596	349.637
E. angolense	*T. scleroxylon*	-300.7167*	16.8617	.000	-345.737	-255.696
	C. gabunensis	28.2250	16.8617	.349	-16.796	73.246
	P. macrocarpa	-304.6167*	16.8617	.000	-349.637	-259.596

*. The mean difference is significant at the 0.05 level.

5.5.2. Chemical analysis of wood residues

The results of the chemical analysis for Wood Residues for *C. gabunensis*, *E. angolense*, *T. scleroxylon* and *P. macrocarpa* are presented in Tables 5.4 and 5.5.

Table 5.4 Some chemical composition of the wood residues used in the study.

Organic material (%)	N	P	K	Ca	Mg	Lignin	Organic Carbon
C. *gabunensis*	0.140	0.02	0.020	0.220	0.190	26.000	49.400
E. *angolense*	0.140	0.09	0.050	0.540	0.130	39.000	47.900
T. *scleroxylon*	0.070	0.14	0.070	0.770	0.760	18.000	48.100
P. *macrocarpa*	0.280	0.09	0.060	0.900	0.110	39.000	47.800

Values are means of triplicate samples (Source: Field Survey, 2012)

Table 5.4 shows that the nitrogen content of the wood residues ranged between 0.070% for *T. scleroxylon* and 0.280% for *P. macrocarpa*. *C. gabunensis* and *E. angolense* had the same levels of nitrogen (0.140%). Phosphorus content was greatest for *T. scleroxylon* (0.14%) and lowest for *C. gabunensis* (0.02%). *E. angolense* and *P. macrocarpa* had the same level of phosphorus (0.09%). Potassium content varied from 0.020% for *C. gabunensis* to 0.070% for *T. scleroxylon. E. angolense* and *P. macrocarpa* had 0.050% and 0.060% levels of potassium respectively. Calcium content was greatest for *P. macrocarpa* (0.900%) and lowest for *C. gabunensis* (0.220%). *T. scleroxylon and E. angolense* had 0.770% and 0.540% levels of Calcium respectively. Magnesium content ranged between 0.110% for *P. macrocarpa* and 0.760% for *T. scleroxylon.*

Carbon ranged between 47.800% for *P. macrocarpa* and 49.400% for *C. gabunensis.* Lignin content was lowest for *T. scleroxylon* (18.000%) and greatest for *E. angolense* and *P. macrocarpa* (39.000%).

Table 5.5 C/N, C/P and Lignin/N ratios of the Wood Residues used in the study.

Organic material	C/N Ratio	C/P Ratio	Lignin/ N Ratio
C. gabunensis	352.857	2,470.000	185.714
E. angolense	342.143	5,322.222	278.571
T. scleroxylon	687.143	343.571	257.143
P. macrocarpa	170.714	531.111	139.286

Values are means of triplicate samples (Source: Field Survey, 2012)

Results from Table 5.5 show that the C/N ratio ranged from 170.714 for *P. macrocarpa* to 687.143 for *T. scleroxylon.* The C/P ratio ranged from 343.571 for *T. scleroxylon to* 5,322.222 for *E. angolense.* The Lignin/N ratio ranged from 139.286 for *P. macrocarpa* and 278.571 for *E. angolense.*

5.5.3. Wood residue decomposition

Decomposition of buried and surface applied (dump) wood residues was assessed. Rates of residue decomposition were measured as mass loss with time (Appendix VIII). There was a general decline in the percentage mass remaining of all the wood residues with time of decomposition. The decomposition rates were much pronounced between Weeks 6 and 8. In comparing the decomposition rates for the dump and buried, even though there was a general decline in the dry matter of residues, there was no particular trend between the dump and buried. At the end of Week 12 (three months), none of the wood species had less than 50% of their initial mass remaining.

Analysis of Variance (ANOVA) test to determine if there were any significant differences between the decomposition rates of residues of the selected species was conducted. Table

5.6 provides some very useful descriptive statistics, including the mean, standard deviation and 95% confidence intervals for the dependent variable (Decomposition: dump and buried) for each separate species (*C. gabunensis*, *E. angolense*, *P. macrocarpa* and *T. scleroxylon*), as well as when all species are combined (Total).

Table 5.6 ***The descriptive and Confidence Interval Table***

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Dump	*T. scleroxylon*	21	86.3386	12.51918	2.73191	80.6399	92.0372	67.83	100
	C. gabunensis	21	83.5686	10.13915	2.21254	78.9533	88.1839	69.9	100
	P. macrocarpa	21	83.9205	15.0717	3.28892	77.0599	90.781	65.03	100
	E. angolense	21	83.5443	12.6102	2.75177	77.8042	89.2844	65.77	100
	Total	84	84.343	12.52827	1.36695	81.6242	87.0618	65.03	100
Buried	*T. scleroxylon*	21	89.9986	11.48866	2.50703	84.769	95.2281	72.31	100
	C. gabunensis	21	85.9557	12.3992	2.70573	80.3117	91.5998	70.99	100
	P. macrocarpa	21	84.7133	9.92239	2.16524	80.1967	89.23	70	100
	E. angolense	21	85.0371	11.71482	2.55638	79.7046	90.3697	69.99	100
	Total	84	86.4262	11.40872	1.24479	83.9503	88.902	69.99	100

From Table 5.6, when the residues were dumped, *T. scleroxylon* recorded the highest rate of decomposition (86.3386 ± 12.51918), compared to the other species. Again, when the residues were buried, *T. scleroxylon* registered the highest rate of decomposition (89.9986 ± 11.48866) compared with the other species. When dumped, the 95% confidence interval for the mean decomposition rate of *T. scleroxylon* was (80.6399, 92.0372). This means that it is 95% sure that the mean decomposition rate lies in the interval. The test for the differences in decomposition rate of the residues of the various species is shown in the ANOVA table (Table 5.7).

Table 5.7 shows the ANOVA analysis and whether there is statistically significant difference between the decomposition rate of residues of the species (*T. scleroxylon*, *C. gabunensis*, *P. macrocarpa* and *E. angolense*). According to Table 5.7, the significance level is p = 0.872 when dumped and p = .0.417 when buried. Clearly, the p-values are all greater than the risk value (0.05), therefore, none of them is said to be statistically significant. This means that there are no decomposition rate significant differences among the residues of the species in all the experiments (dumped and buried). As a result, there is no need for further **Multiple Comparisons test (**post-hoc tests).

Table 5.7 ***The ANOVA Table of the Decomposition Rate of the Residues of the Species when Dumped and Buried***

ANOVA						
		Sum of Squares	d.f.	Mean Square	F	Sig.
Dump	Between Groups	113.4	3	37.79	0.234	0.872
	Within Groups	12914	80	161.426		
	Total	13027	83			
Buried	Between Groups	374.8	3	124.926	0.958	0.417
	Within Groups	10428	80	130.355		
	Total	10803	83			

MANOVA test was conducted to find out whether for a particular species, the decomposition rate of the residue was different when dumped and buried. Clearly, there were no significant differences between decomposition rate of the residues of any of the species when dumped or buried. This is so since all the p – values are greater than the risk value = 0.05.

Table 5.8 ***The MANOVA Table of the Decomposition Rate of the Residues of the Species when Dumped and Buried (Pairwise Comparisons)***

Dependent Variable	(I) Dumped or Buried	(J) Dumped or Buried	Mean Difference (I-J)	Std. Error	P -values	95% Confidence Interval for Difference: Lower Bound	95% Confidence Interval for Difference: Upper Bound
Wawa	Dumped	Buried	-3.660	3.708	.330	-11.154	3.834
	Buried	Dumped	3.660	3.708	.330	-3.834	11.154
Koto	Dumped	Buried	-.793	3.938	.841	-8.751	7.165
	Buried	Dumped	.793	3.938	.841	-7.165	8.751
Edinam	Dumped	Buried	-1.493	3.756	.693	-9.084	6.098
	Buried	Dumped	1.493	3.756	.693	-6.098	9.084
Denya	Dumped	Buried	-2.387	3.495	.499	-9.451	4.677
	Buried	Dumped	2.387	3.495	.499	-4.677	9.451

5.6 Discussion

5.6.1. Water holding capacity of wood residues

Results from Figure 5.1 show that *T. scleroxylon* and *P. macrocarpa* had higher water holding capacity as compared to *E. angolense* and *C. gabunensis*. There were no significant differences between *T. scleroxylon* and *P. macrocarpa*. Again, there were no significant differences between *C. gabunensis* and *E. angolense.* However there was a significant difference in water holding capacity between *P. macrocarpa* and *C. gabunensis*, as well as between *P. macrocarpa* and *E. angolense* at 95% significance level. According to Tetteh (2004), plant materials with high water holding capacity decomposed faster than low water holding capacity materials which decomposed at lower rates. This implies that a pile of wood residue made up of either *T. scleroxylon* or *P. macrocarpa* is expected to decompose faster than one made up of *E. angolense* or *C. gabunensis.*

5.6.2 Chemical analysis of wood residues

The three main factors which control the decomposition process are the quality of the decomposing organic material, the decomposer organisms and the environmental conditions (Swift *et al.,* 1979). According to Tetteh (2004), organic material with high nutrient content and high rate of decomposition could be used directly to fertilize crops. He also stated that plant materials with C/P ratio greater than 300 indicate that they are of low quality. Thus *C. gabunensis* and *E. angolense* are the lowest in quality (Table 5.1).

Acooding to Tetteh (2004)"s analysis none of the wood residues could be used directly as fertilizer since they have C/P ratio greater than 300, however they could be incorporated in the soil as soil amendment to improve the soil structure as well as acting as mulch to protect the soil from direct sunshine and rain.

5.6.3 Wood residue decomposition

The use of unconfined residues (residues spread on the surface of soil) in decomposition comes close to what happens naturally. However, monitoring of decomposition can only be possible in the use of decomposition bags which make it possible to recover the residual experimental material even after the material has undergone some decomposition (Anderson and Ingram, 1993). Decomposition bags have been used by several other workers to study plant residue decomposition, including Tetteh (2004).

According to Tetteh (2004) plant residues decompose faster when buried than when placed on the soil surface. However, in Figures 5.4 – 5.7., at some point the dump was decomposing faster, while at some other point the buried was decomposing faster (reference to percentage mass of residue remaining). This may be attributed to the invasion of termites. It is most likely that the termites moved from their locality to the plots on the surface of the soil rather than from within the soil since more were found in the dump than the buried samples (termite in dump: buried = 2:1). They probably fed on more of the dump residues than on the buried residues. Swift *et al.,* (1979) found out that the three main factors which control the decomposition process are the quality of the decomposing organic material, the decomposer organisms and the environmental conditions. In this case it is probable that the decomposer organism played a major role in the decomposition of the surface applied or dump wood residue.

5.7. Conclusion

In the sawmills, there are different species and their sawdust give varying nutrient contents. *T. scleroxylon* and *P. macrocarpa* were richer in nutrients and hence decomposed faster. A pile of wood residue made up of either *T. scleroxylon* or *P. macrocarpa* is expected to decompose faster than one made up of *E. angolense* or *C. gabunensis*. Generally sawdust residues decomposed at a very low rate (only about 35% decomposition of test samples during three months). The low rate of decomposition obtained were probably due to the higher lignin contents of the residues.

The study has added to knowledge on the quality, water holding ability and decomposition of some common wood sawdust. The study has also established that the rate of decomposition of sawdust depended more on lignin content. It was expected that the rate of decomposition of the buried sawdust would be faster than the surface applied sawdust but there was no significant difference between the two. The study has also demonstrated that the peak of decomposition of the test samples was 6^{th} to 8^{th} week.

5.8. Recommendation

The study showed that it took quite a long time for the sawdust to decompose. It is better to use the sawdust for chipboard or briquette and if there is a need for soil amendment then biochar is better.

CHAPTER SIX

6.0 SOME ENVIRONMENTAL IMPLICATIONS OF WOOD RESIDUES

6.1 Introduction

The FAO predicts that global consumption of industrial wood products will increase by 45% in 2020, and the experts are concerned about the additional pressure this will put on the world‟s forest (FAO, 2001). Preventing wood waste in the timber sector by improving the efficiency of wood processing could help to reduce environmental impact and also meet the increasing demand for wood without further impacting the world‟s forest (Magin, 2001). Recycling is primarily considered to reduce the use of virgin forest.

Forests in general provide a wide range of socio-economic and environmental benefits to all Ghanaians. Forests play a major role in the growth and development of the Ghanaian economy and in the maintenance of environmental quality (EPA, 1998). From the environmental perspective, these diminishing forests are causing widespread fears of desertification. This has a dramatic effect on the country‟s whole vegetation and climate change by causing an increase in carbon dioxide levels in the atmosphere and increasing greenhouse effect (EPA, 1998). A green economy is an economy that generates prosperity while maintaining a healthy environment for future generation (EEA, 2011) by reducing environmental impacts from raw material extraction and materials processing.

Sawdust is the only residue in significant surplus for increasing offsite residue utilization (Odoom, 2004). Very little potential exist for increasing the direct utilization of surplus sawdust because of technical and economic constraints. Wood dust has several hazards associated with exposure to it in the workplace. In general, exposure to excessive amounts is considered to have an irritant effect on eyes, nose and throat in addition to pulmonary function impairment and is considered a human carcinogen https://www.osha.gov/SLTC/wooddust/index.html#eTools. The presence of wood residue at dumping sites close to the sawmills mar the scenic beauty of the surrounding area and cause health challenges to the inhabitants.

6.2 Objectives

The specific objectives were as follows:

- To identify constraints in handling sawdust for power generation and the effect on the environment.
- To find out some health related issues associated with sawdust and smoke from burning the sawdust.

6.3 Materials and Methods

6.3.1 Description of study areas

The sawmill sector of the study areas disposed off some of their residues through environmentally incorrect means. Companies C and D dumped their residues at a designated place on their compound. Their dumping sites were at secluded areas near the boundaries of the industries where the residues were burnt openly. Companies A and B sent their own to a common dumping site and burnt openly. They shared a common dumping site with other timber industries.

6.3.2 Data collection

Data was collected through personal observation, laboratory work and interview.

6.3.2.1 Personal observation

On the factory floor, a number of technical and organizational constraints caused sawdust to go unutilized. The activities during processing and at the dumping site were observed and special attention was given to the ways wood residues were disposed off. In order to assess other factors related to disposal of the wood residues at the dumping site, the following inquiries were made and recorded:

- The source of the wood residue
- The volume of the truck used
- How often sawdust was disposed on the average for a day
- How often the sawdust was burnt within a week.

6.3.2.2 Laboratory work

Samples of sawdust of the species used were collected during the production process to test for their moisture contents. These samples were directly collected in Ziploc plastic bags from the two companies in Ashanti region and sent to the laboratory for the test during November, 2012. Ten grams of each species was taken, with three replicates. The samples were labeled and the initial weights were taken using an electronic balance. The samples were placed in a foil, put in a laboratory oven and run at a temperature of 70^oC for 48 hours and weighed until a constant mass was achieved. This was the oven dry mass.

According to Simpkins (2006), the moisture content (MC) of wood is expressed as

$$MC\ (\%) = \frac{(\text{Initial mass} - \text{Oven dry mass}) \times 100}{\text{Oven dry mass}}$$

Rapidity of weighing is of particular importance when the samples are oven dried, as sawdust with large surface area is likely to absorb moisture in a very short period. The samples taken should also be free from oils used in lubricating the sawing machines. The presence of oils can introduce some errors in the calculation of moisture content by oven dry method. These substances being volatile are lost in the process of drying and are counted as moisture (Djombo, 2003). The moisture content of the sawdust has a marked effect on the rate at which it will burn.

6.3.2.3 Interviews

Interviews were conducted to find out the perceived effects of wood residue (Appendix Id). This was done within a 300 metre radius of the burning site. Purposive sampling was used. This was based on individuals who had stayed close to the site for more than one year. A health checklist on wood dust and smoke was used. A total of twenty (20) people were interviewed, twelve (12) from the common dumping site and two (2) each from the study Companies (Appendix IX and Appendix X).

6.3.3 Data Analysis

Data were analyzed using Microsoft Excel and presented in Tables.

6.4 Results

6.4.1 Constraints in handling and use of sawdust for power

The mills visited employed water spray for the lubrication of band saw and circular saw blades used in log breakdown. The water was sprayed in excess amount, wetting the sawdust. This made it very difficult to combust without pre-drying, and this is one cause of low utilization of sawdust as a boiler fuel. Also lack of storage facilities caused the sawdust to be stored outdoors, exposing them to environmental conditions such as rain water and moisture from the atmosphere rendering the sawdust difficult to burn. The furnaces utilized in the study sawmills were designed to burn solid wood fuels to raise heat and steam. The large holes (5cm×5cm) resulted in sawdust fuels falling through the grates.

The moisture content of the sawdust is given in Table 6.1. This shows that *C. gabunensis* had the lowest moisture content (49.25%) and *T. scleroxylon* had the highest moisture content (76.68%). The average moisture content of all the samples used was 63.90%, this made it difficult to use the sawdust as a boiler fuel.

Table 6.1 Moisture content of the sawdust used for the experiment

Wood species	Initial Mass (g)	Oven dry Mass (g)	Moisture content (%)
C. gabunensis	10.000	6.700	49.25
E. angolense	10.000	6.300	58.73
P. macrocarpa	10.000	5.850	70.94
T. scleroxylon	10.000	5.660	76.68

Values are means of triplicate samples (Source: Field Survey, 2012)

$$\text{Average Moisture content (\%)} = \frac{49.25+58.73+70.94+76.68}{4}\ (\%) = \mathbf{63.90\%}$$

6.4.2 Some health related issues associated with sawdust and smoke from burning the sawdust.

Wood residues from about seven (7) sawmills were dumped at the common dumping site close to the industries. Vehicles used for disposing off the sawdust varied in cubic capacity from tractors (1.80m^3), through Kia trucks (3.00m^3) to tipper trucks (7.00m^3). On the average about ten (10) tipper trucks full of sawdust (70.00m^3) were sent to the dumping site everyday. These residues were burnt openly twice in a week. However, because of the high moisture content, they were not able to burn completely, always leaving some amount of wood residues on the site (Plate 6.1).

Plate 6.1 Sawdust burning at dumping site near the timber industries in Ashanti Region (Source: Field Survey, 2012)

This resulted in the production of smoke, particles and toxic gases. In an interview with some residents around the dumping sites, they complained of nasal irritation, throat irritation, chest pain and itchy eyes. It was also observed that the place was aesthetically unclean and the whole scene was a real fire hazard to the surrounding companies. The information of the residents interviewed is recorded in Appendix VII. Majority of the respondents were male (55%), 60% aged between 40 – 59 years, 45% had no formal education, 65% migrants and 85% of the respondents had worked at the place for more than 8 years.

Table 6.2 Types of health problems faced by Respondents affected by sawdust

Types of Health Problems faced	No. of Respondents experiencing Problem	Respondents (%)
Nasal irritation	13	65
Nasal bleeding	0	0
Prolonged cold	6	30
Itching skin	7	35
Cracking skin	0	0
Throat irritation	12	60
Eye irritation	10	50
Chest pain	3	15
Fast heart beat	0	0
Joint pain	0	0

(Source: Field Survey, 2012)

Various types of health problems faced by the respondents are presented in Table 6.2. Majority of the respondents felt nasal irritation (65%), followed by throat irritation (60%), eye irritation (50%), itching skin (35%), prolonged cold (30%) and chest pain (15%). None of the respondents experienced nasal bleeding, cracking skin, fast heart beat and joint pain.

6.5 Discussion

6.5.1 Constraints in use of sawdust for power

This study reported a yield of about 38.08%, thus a high percentage of wood residues (61.92%). Wood residues like sawdust, trimmings and edgings are typically viewed as a burdensome disposal problem (FAO, 1990). Sawdust formed majority of the wood residue that was not utilized (60% of sawdust discarded). This is in line with Odoom (2004), who stated that sawdust is the only residue in significant surplus for increasing off site residue utilization. Not only does the accumulation of sawdust pose danger of fire, sawmilling running cost are also increased owing to the need to dispose of the accumulated sawdust (Ocloo and Yeboah, 1980).

At the study areas, sawdust went through a lot of challenges which rendered its use difficult. Water sprayed to lubricate band saw and circular saw blades during production process was in excess amount. When samples of the sawdust were tested in the laboratory, an average of 63.90% was recorded. The moisture content of more than 60% of the sawdust makes it very difficult to burn. The energy efficiency of burning wood residue is directly related to the moisture content of the wood residue (Samis *et al.*, 1999). The drier the wood, the greater its heat yield (JUCA, 2011). A portion of the energy in the wood is used to eliminate the water. Consequently, higher moisture content implies lower energy content (Simpkins, 2006). A large portion of the sawdust could therefore not burn due to the high moisture content. There were also no storage facilities in the study areas to store sawdust for the future. Wood being hygroscopic in nature absorbed a lot of moisture, increasing its already high moisture content. The sawdust could neither be used directly to feed the furnace to generate heat nor steam since the grates were too large (5cm×5cm) to support the sawdust during combustion.

6.5.2 Some health hazards of sawdust

Sawdust formed majority of the wood residue that was not utilized and was discarded by open burning. It poses several challenges to the environment and health of workers in the timber industries (Lasode *et al.*, 2013). Wood dust becomes a potential health problem when the particles become airborne. Breathing these particles may cause allergic respiratory symptoms. https://www.osha.gov/SLTC/wooddust/index.html#eTools. In addition to the health effects of wood dust, airborne dust can create the potential for a dust explosion (OSHA, 2012), which can burn down an entire timber industry. This can cause financial loss to the timber industry.

An interview with some residents around the dumping site revealed that, they had frequent irritation in the nose, throat and eye, cold and chest pains. This proved work done by EPA (2013), which reported that backyard burning of wood waste can increase the risk of heart diseases, aggravate respiratory ailment such as emphysema, and cause nausea or headaches. At times the sawdust was heaped at the dumping site for a very long period before burning, thus becoming breeding spaces for worms and germs, liberating obnoxious odour and exposing workers to unhygienic working environment (Dosunmu and Ajayi, 2002). Sawdust therefore has to be utilized for economic benefits and to reduce environmental impact in society.

6.6 Conclusion

The moisture content of more than 60% of the sawdust makes it difficult or impossible to combust without pre-drying, and this is one cause of low utilization of sawdust as a boiler fuel. Lack of storage facilities for sawdust as well as the large grate holes in the furnace hindered the use of sawdust for fuel. Its accumulation at the dumping site also caused challenges to the environment and health of the residents around the dumping site.

6.7 Recommendations

Despite the variable end-uses of wood residues, there were still coarse and fine residues that were not being utilized. This suggests that there is clear need for identification of new markets for wood residues. Sawdust could be used for briquette manufacture for household use or for the manufacture of biochar for soil amendment. Considerable modification of grates in the furnace would improve the use of sawdust for energy and power in the timber industries. Sawdust sheds should be provided to protect the residues from environmental hazards. Periodic environmental audit and Environmental Management Plan is very necessary.

CHAPTER SEVEN

7.0 GENERAL CONCLUSION AND RECOMMENDATIONS

7.1 General Conclusion

Sawmilling has always been associated with residue production but with the trend of log shortage, residue generated during sawmilling need to be reduced to the barest minimum to minimize the rate of log extraction from the forest and increase mill productivity. The lower the lumber recovery, the more raw materials (logs) that must be processed daily in order to meet production target.

The present study constitutes an attempt to promote the use of abundant but overlooked wood residues in Ghana through providing trustworthy data about the various types, quantities and current uses. The study includes an extensive review on the production process of lumber and the various types of wood residues.

It was realized from the study that, the amount of residues generated in the sawmills was more than 60% of their input volume. The edger generated about 43% of all residues produced during the sawmilling production process. The edger produced the highest volume of coarse residue, but the volume of sawdust residue (SR) was highest at the bandmill. The various types of wood residues identified in the production processes were sawdust; slabs; edgings; and trimmings.

The study revealed that residues generated has no economic benefit to the study sawmills as long as judicious and optimum economic uses are not found for them. The lesser the quantities of residues generated, the better the sawmill profitability. Thus wood residues have negative effect on sawmill profitability. To combat decrease in raw material availability, sawmills need to improve their sawn wood recovery and add value to the residues to reduce the residues to the rarest minimum. It was realized that low recovery results in increased cost per unit output and the use of coarse wood residues generated in sawmilling as fuel to the furnace was not economically efficient, rather it was negative to sawmill productivity.

The study has added to knowledge on the quality, water holding ability and decomposition of some common wood sawdust. Generally sawdust residues decomposed at a very low rate (only about 35% decomposition of test samples during three months). The low rate of decomposition obtained depended more on lignin content. There was no significant difference between the rate of decomposition of the buried sawdust and the surface applied sawdust.

Lack of storage facilities for sawdust with moisture content more than 60% as well as the large grate holes in the furnace at the sawmills hindered the use of sawdust for fuel. It accumulated and caused challenges to the environment and health of the residents around the dumping site.

The data provided could be used in the future planning of wood resource use and waste streams, leading to an overall reduction in wood residue and the development of sector focused sustainable strategies. The data also provides indicators towards a more cost effective management of wood flow. The study will also help increase the scientific data base of the selected species and their utilization.

7.2 Recommendations

- A logical continuation of this study could be some further investigations on other popular timber species in Ghana.
- In order to ensure the efficient use of wood residue in Ghana and to protect our forest from deforestation by excessive logging, sawmilling industries would have to educate their staff through research and workshops on recycling a lot more wood residues so as to harvest the forest on a sustainable basis.
- Wood product manufacturers should install and train their workers on the use of laser scanning systems and computer assisted sawing or cutting programmes which will increase volumetric recovery and quality products.
- Wood residue producers should form partnership which would facilitate the transportation, storage and marketing of wood residues. They could also consider value-added manufacturing processes of solid wood residues such as finger joints, crafts and toys, floorings and garden fencing. Also fines like the sawdust could be used to manufacture biochar for soil amendment to enhance nurseries, plantations and other agricultural interests.
- The Government should consider offering investment tax credit, tax deferments or other types of incentives to businesses that are interested in utilizing wood residues in their manufacturing processes.
- Companies should find other means to fuel their boilers, example cogeneration so that, power consumption and use of solid residue for fuel can be reduced.

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APPENDICES

APPENDIX I a. Input and output volumes of wood and residue at Company A for *Triplochiton scleroxylon*

BANDMILL **EDGER** **TRIMMER**

BM **Edged** Input Total

% CR SR log Input log **boards** Residue % CR SR Input BM **boards** Residue edged **Trimmed** Residue % CR SR Residue

Residue (M3) (M3) no. vol.(m3) **vol.(m3)** vol. Residue (m3) (m3) boards(m3) **vol.(m3)** vol. board **lumber(m3)** vol.(m3)

Residue (m3) (m3) (m3)

1 1.098 0.638 0.46 41.89 0.271 0.189 0.638 0.433 0.205 32.13 0.193 0.012 0.433 0.32 0.113 26.10 0.11 0.003 0.778 2 0.637 0.423 0.214 33.59 0.116 0.098 0.423 0.235 0.188 44.44 0.175 0.013 0.235 0.169 0.066 28.09 0.063 0.003 0.468 3 0.634 0.388 0.246 38.80 0.133 0.113

0.388 0.213 0.175 45.10 0.163 0.012 0.213 0.153 0.06 28.17 0.058 0.002 0.481 4 0.673 0.45 0.223 33.14 0.123 0.100 0.45 0.348 0.102 22.67 0.095 0.007 0.348 0.264 0.084 24.14 0.081 0.003 0.409

5 0.833 0.423 0.41 49.22 0.234 0.176 0.423 0.165 0.258 60.99 0.240 0.018 0.165 0.119 0.046 27.88

0.044 0.002 0.714

6 0.776 0.495 0.281 36.21 0.160 0.121 0.495 0.3 0.195 39.39 0.183 0.012 0.3 0.222 0.078 26.00

0.076 0.002 0.554 7 1.178 0.797 0.381 32.34 0.225 0.156 0.797 0.559 0.238 29.86 0.225 0.013

0.559 0.425 0.134 23.97 0.13 0.004 0.753

8 2.152 1.843 0.309 14.36 0.188 0.121 1.843 1.366 0.477 25.88 0.461 0.016 1.366 1.011 0.355 25.99

0.35 0.005 1.141

9 0.665 0.561 0.104 15.64 0.058 0.046 0.561 0.299 0.262 46.70 0.246 0.016 0.299 0.221 0.078 26.09 0.075 0.003 0.444 10 1.346 1.262 0.084 6.24 0.050 0.034 1.262 0.71 0.552 43.74 0.527 0.025 0.71 0.54 0.17 23.94 0.168 0.002 0.806 11 4.271 2.844

1.427 33.41 0.956 0.471 2.844 1.325 1.519 53.41 1.473 0.046 1.325 0.954 0.371 28.00 0.367 0.004 3.317

12 2.346 1.663 0.683 29.11 0.437 0.246 1.663 0.888 0.775 46.60 0.744 0.031 0.888 0.639 0.249 28.04 0.245 0.004 1.707 13 2.268 1.851 0.417 18.39 0.267 0.150 1.851 1.48 0.371 20.04 0.359 0.012 1.48 1.125 0.355 23.99 0.352 0.003 1.143 14 1.661 1.461 0.2 12.04 0.120

0.080 1.461 1.099 0.362 24.78 0.348 0.014 1.099 0.813 0.286 26.02 0.28 0.006 0.848 15 1.617 1.266 0.351 21.71 0.211 0.140 1.266 0.799 0.467 36.89 0.446 0.021 0.799 0.591 0.208 26.03 0.204 0.004 1.026 16 0.753 0.543 0.21 27.89 0.116 0.094 0.543 0.277 0.266 48.99

0.250 0.016 0.277 0.205 0.072 25.99 0.069 0.003 0.548 17 1.997 1.568 0.429 21.48 0.386 0.043 1.568 0.956 0.612 39.03 0.588 0.024 0.956 0.688 0.268 28.03 0.264 0.004 1.309 18 2.678 1.445 1.233 46.04 0.801 0.432 1.445 1.233 0.212 14.67 0.202 0.010 1.233 0.863 0.37

30.01 0.366 0.004 1.815 19 4.016 3.9 0.116 2.89 0.077 0.039 3.9 1.31 2.59 66.41 2.525 0.065 1.31 0.917 0.393 30.00 0.39 0.003 3.099 20 0.816 0.595 0.221 27.08 0.117 0.104 0.595 0.4 0.195 32.77 0.183 0.012 0.4 0.28 0.12 30.00 0.116 0.004 0.536 21 1.27 0.685 0.585 46.06

0.345 0.240 0.685 0.455 0.23 33.58 0.217 0.013 0.455 0.296 0.159 34.95 0.153 0.006 0.974

22 0.719 0.458 0.261 36.30 0.141 0.120 0.458 0.196 0.262 57.21 0.244 0.018 0.196 0.129 0.067 34.18 0.062

0.005 0.59 23 0.848 0.587 0.261 30.78 0.149 0.112 0.587 0.281 0.306 52.13 0.288 0.018 0.281 0.208 0.073

25.98 0.07 0.003 0.64

24 0.902 0.675 0.227 25.17 0.137 0.090 0.675 0.398 0.277 41.04 0.262 0.015 0.398 0.314 0.084 21.11 0.081

0.003 0.588 25 0.738 0.445 0.293 39.70 0.161 0.132 0.445 0.212 0.233 52.36 0.217 0.016 0.212 0.148 0.064

30.19 0.06 0.004 0.59

26 1.587 1.368 0.219 13.80 0.131 0.088 1.368 0.91 0.458 33.48 0.437 0.021 0.91 0.71 0.2 21.98 0.197 0.003 0.877 27 1.792 1.599 0.193 10.77 0.125 0.068 1.599 1.155 0.444 27.77 0.428 0.016 1.155 0.878 0.277 23.98 0.275 0.002 0.914 28 1.95 1.511 0.439 22.51 0.288 0.151

1.511 1.099 0.412 27.27 0.396 0.016 1.099 0.835 0.264 24.02 0.261 0.003 1.115 29 0.433 0.372 0.061 14.09 0.035 0.026 0.372 0.18 0.192 51.61 0.179 0.013 0.18 0.137 0.043 23.89 0.041 0.002 0.296

30 4.016 3.028 0.988 24.60 0.642 0.346 3.028 2.579 0.449 14.83 0.439 0.010 2.579 2.089 0.49 19.00 0.485 0.005 1.927

TOTAL	**46.670**	**35.144**	**11.526**	**24.70**	**7.200**	**4.326**	**35.144**	**21.860**	**13.284**	**37.80**	**12.733**	**0.551**	**21.860**	**16.263**	**5.597**	**25.60**	**5.493**	**0.104**	30.407
MEAN	**1.556**	**1.171**	**0.384**		**0.240**	**0.144**	**1.171**	**0.729**	**0.443**		**0.42**	**0.02**	**0.729**	**0.542**	**0.187**		**0.18**	**0.00**	1.014
STANDARD DEVIATION	**1.05**	**0.88**	**0.32**				**0.88**	**0.55**	**0.48**				**0.55**	**0.43**					

APPENDIX I

CR= Coarse Residue; SR= Sawdust

APPENDIX I b Input and output volumes of wood and residue at Company A for *Cylicodiscus gabunensis*

	BANDMILL										EDGER						TRIMMER		
SR Residue (m3) (m3) (m3)	Input	**Edged**	CR	SR	Total log	log	**BM boards**	Residue	%	CR	SR	Input BM	**boards**	Residue	% Residue	Input edged	**Trimmed**	Residue	%
											(M3) (M3) no. vol.(m3) **vol.(m3)** vol. Residue (m3) (m3) boards(m3) **vol.(m3)** vol. board **lumber(m3)** vol.(m3) Residue CR								
1	1.489	1.047	0.442	29.68	0.336	0.106	1.047	0.639	0.408	38.97	0.387	0.021	0.639	0.475	0.164	25.67	0.161	0.003	1.014
2	1.162	0.821	0.341	29.35	0.242	0.099	0.821	0.494	0.327	39.83	0.3	0.027	0.494	0.366	0.128	25.91	0.122	0.006	0.796
3	1.569	1.119	0.45	28.68	0.288	0.162	1.119	0.688	0.431	38.52	0.413	0.018	0.688	0.512	0.176	25.58	0.171	0.005	1.057
4	1.957	1.385	0.572	29.23	0.432	0.14	1.385	0.87	0.515	37.18	0.494	0.021	0.87	0.65	0.22	25.29	0.215	0.005	1.307
5	1.827	1.293	0.534	29.23	0.401	0.133	1.293	0.813	0.48	37.12	0.457	0.023	0.813	0.607	0.206	25.34	0.201	0.005	1.22
6	2.097	1.489	0.608	28.99	0.374	0.234	1.489	0.941	0.548	36.80	0.515	0.033	0.941	0.707	0.234	24.87	0.227	0.007	1.39
7	1.677	1.186	0.491	29.28	0.33	0.161	1.186	0.729	0.457	38.53	0.438	0.019	0.729	0.545	0.184	25.24	0.179	0.005	1.132
8	1.203	0.845	0.358	29.76	0.27	0.088	0.845	0.51	0.335	39.64	0.314	0.021	0.51	0.378	0.132	25.88	0.125	0.007	0.825
9	2.298	1.627	0.671	29.20	0.52	0.151	1.627	1.049	0.578	35.53	0.556	0.022	1.049	0.79	0.259	24.69	0.252	0.007	1.508
10	2.198	1.648	0.55	25.02	0.441	0.109	1.648	1.061	0.587	35.62	0.568	0.019	1.061	0.9	0.161	15.17	0.152	0.009	1.298
11	1.564	1.103	0.461	29.48	0.386	0.075	1.103	0.678	0.425	38.53	0.4	0.025	0.678	0.504	0.174	25.66	0.169	0.005	1.06
12	1.211	0.85	0.361	29.81	0.328	0.033	0.85	0.514	0.336	39.53	0.317	0.019	0.514	0.381	0.133	25.88	0.125	0.008	0.83
13	0.743	0.519	0.224	30.15	0.193	0.031	0.519	0.306	0.213	41.04	0.186	0.027	0.306	0.226	0.08	26.14	0.076	0.004	0.517

Log no.	Input log vol. (m3)	Bandmill vol.(m3)	Residue vol. (m3)	% Residue	CR (m3)	SR (m3)	Input vol.	Edger vol.	Residue vol.	% Residue	CS (m3)	SR (m3)	Input vol.	Trimmer vol.	Residue vol.	% Residue	CR (m3)	SR (m3)	Total Residue (m3)
14	0.884	0.617	0.267	30.20	0.24	0.027	0.617	0.365	0.252	40.84	0.227	0.025	0.365	0.268	0.097	26.58	0.092	0.005	0.616
15	1.054	0.738	0.316	29.98	0.227	0.089	0.738	0.439	0.299	40.51	0.274	0.025	0.439	0.322	0.117	26.65	0.112	0.005	0.732
TOTAL	**22.93**	**16.287**	**6.646**	**28.98**	**5.008**	**1.638**	**16.287**	**10.096**	**6.191**	**38.01**	**5.846**	**0.345**	**10.096**	**7.631**	**2.465**	**24.42**	**2.379**	**0.086**	**15.302**
MEAN	**1.529**	**1.086**	**0.443**		**0.334**	**0.109**	**1.086**	**0.673**	**0.413**		**0.390**	**0.023**	**0.673**	**0.509**	**0.164**		**0.159**	**0.006**	**1.020**
STAND. D	**0.48**	**0.35**	**0.13**		**0.09**	**0.06**	**0.35**	**0.24**	**0.12**		**0.12**	**0.00**	**0.24**	**0.19**	**0.05**		**0.05**	**0.00**	**0.29**

CR= Coarse Residue; SR= Sawdust

c. Input and output volumes of wood and residue at Company B for *Triplochiton scleroxylon*

BANDMILL EDGER TRIMMER

Log no.	Input log vol. (m3)	**Bandmill vol.(m3)**	Residue vol. (m3)	% Residue	CR (m3)	SR (m3)	Input vol.	**Edger vol.**	Residue vol.	% Residue	CS (m3)	SR (m3)	Input vol.	**Trimmer vol.**	Residue vol.	% Residue	CR (m3)	SR (m3)	Total Residue (m3)
1	1.609	1.451	0.158	9.82	0.109	0.049	1.451	0.986	0.465	32.05	0.444	0.021	0.986	0.749	0.237	24.04	0.233	0.004	0.86
2	1.762	1.485	0.277	15.72	0.180	0.097	1.485	0.687	0.798	53.74	0.753	0.045	0.687	0.481	0.206	29.99	0.200	0.006	1.281
3	1.405	1.148	0.257	18.29	0.152	0.105	1.148	0.79	0.358	31.18	0.340	0.018	0.79	0.585	0.205	25.95	0.202	0.003	0.82
4	1.817	1.536	0.281	15.47	0.171	0.110	1.536	0.281	1.255	81.71	1.205	0.050	0.281	0.185	0.096	34.16	0.092	0.004	1.632
5	0.902	0.674	0.228	25.28	0.128	0.100	0.674	0.398	0.276	40.95	0.260	0.016	0.398	0.295	0.103	25.88	0.100	0.003	0.607
6	0.738	0.445	0.293	39.70	0.187	0.106	0.445	0.212	0.233	52.36	0.217	0.016	0.212	0.167	0.045	21.23	0.043	0.002	0.571

APPENDIX I

7		1.587	1.368	0.219	13.80	0.140	0.079	1.368	0.91	0.458	33.48	0.437	0.021	0.91	0.673	0.237	26.04	0.234	0.003	0.914
8		1.792	1.599	0.193	10.77	0.116	0.077	1.599	1.155	0.444	27.77	0.426	0.018	1.155	0.855	0.3	25.97	0.298	0.002	0.937
9		1.961	1.443	0.518	26.42	0.342	0.176	1.443	1.052	0.391	27.10	0.373	0.018	1.052	0.789	0.263	25.00	0.260	0.003	1.172
10		0.708	0.589	0.119	16.81	0.064	0.055	0.589	0.337	0.252	42.78	0.238	0.014	0.337	0.246	0.091	27.00	0.089	0.002	0.462
11		1.823	1.666	0.157	8.61	0.108	0.049	1.666	1.243	0.423	25.39	0.408	0.015	1.243	0.957	0.286	23.01	0.283	0.003	0.866
12		2.034	1.823	0.211	10.37	0.131	0.080	1.823	0.933	0.89	48.82	0.862	0.028	0.933	0.7	0.233	24.97	0.231	0.002	1.334
13		0.908	0.711	0.197	21.70	0.114	0.083	0.711	0.537	0.174	24.47	0.165	0.009	0.537	0.419	0.118	21.97	0.116	0.002	0.489
14		1.961	1.543	0.418	21.32	0.272	0.146	1.543	1.052	0.491	31.82	0.471	0.020	1.052	0.831	0.221	21.01	0.219	0.002	1.13
15		1.95	1.609	0.341	17.49	0.232	0.109	1.609	1.202	0.407	25.30	0.393	0.014	1.202	0.889	0.313	26.04	0.310	0.003	1.061
16		2.814	2.436	0.378	13.43	0.242	0.136	2.436	1.689	0.747	30.67	0.726	0.021	1.689	1.326	0.363	21.49	0.359	0.004	1.488
17		2.248	1.97	0.278	12.37	0.170	0.108	1.97	1.455	0.515	26.14	0.499	0.016	1.455	1.12	0.335	23.02	0.333	0.002	1.128
18		2.626	2.069	0.557	21.21	0.373	0.184	2.069	1.735	0.334	16.14	0.324	0.010	1.735	1.388	0.347	20.00	0.343	0.004	1.238
19		1.618	1.399	0.219	13.54	0.131	0.088	1.399	0.798	0.601	42.96	0.573	0.028	0.798	0.63	0.168	21.05	0.165	0.003	0.988
20		2.029	1.851	0.178	8.77	0.112	0.066	1.851	0.914	0.937	50.62	0.907	0.030	0.914	0.676	0.238	26.04	0.234	0.004	1.353
	Total	34.292	28.815	5.477	**15.97**	3.474	2.003	28.815	18.366	10.449	**36.26**	10.021	0.428	18.366	13.961	4.405	**23.98**	4.344	0.061	20.331
	Mean	1.715	1.441	0.274		0.174	0.100	1.441	0.918	0.522		0.501	0.021	0.918	0.698	0.220		0.217	0.003	1.017
	SD	0.55	0.50	0.11				0.50	0.42	0.27				0.42	0.34	0.09				

CR= Coarse Residue; SR= Sawdust

APPENDIX I

d Input and output volumes of wood and residue at Company B for *Cylicodiscus gabunensis*

	BANDMILL							EDGER						TRIMMER					
log no.	Input log vol.(m3)	**BM boards vol.(m3)**	Residue vol.	% Residue	CR (m3)	SR (m3)	Input BM boards(m3)	**Edged boards vol.(m3)**	Residue vol.	% Residue	CR (M3)	SR (M3)	Input edged board	**Trimmed lumber(m3)**	Residue vol.(m3)	% Residue	CR (m3)	SR (m3)	Total Residue (m3)
1	1.634	1.152	0.482	29.50	0.356	0.126	1.152	0.732	0.42	36.46	0.395	0.025	0.732	0.556	0.176	24.04	0.171	0.005	1.078
2	2.519	1.802	0.717	28.46	0.583	0.134	1.802	1.171	0.631	35.02	0.595	0.036	1.171	0.884	0.287	24.51	0.281	0.006	1.635
3	2.298	1.632	0.666	28.98	0.544	0.122	1.632	1.044	0.588	36.03	0.555	0.033	1.044	0.786	0.258	24.71	0.253	0.005	1.512
4	1.708	1.204	0.504	29.51	0.415	0.089	1.204	0.746	0.458	38.04	0.433	0.025	0.746	0.566	0.18	24.13	0.176	0.004	1.142
5	1.7	1.253	0.447	26.29	0.386	0.061	1.253	0.777	0.476	37.99	0.457	0.019	0.777	0.577	0.2	25.74	0.192	0.008	1.123
6	1.72	1.214	0.506	29.42	0.385	0.121	1.214	0.754	0.46	37.89	0.438	0.022	0.754	0.564	0.19	25.20	0.185	0.005	1.156
7	0.949	0.662	0.287	30.24	0.244	0.043	0.662	0.395	0.267	40.33	0.225	0.042	0.395	0.292	0.103	26.08	0.096	0.007	0.657
8	2.37	1.687	0.683	28.82	0.439	0.244	1.687	1.093	0.594	35.21	0.540	0.054	1.093	0.82	0.273	24.98	0.268	0.005	1.55
9	2.529	1.825	0.704	27.84	0.535	0.169	1.825	1.197	0.628	34.41	0.604	0.024	1.197	0.907	0.29	24.23	0.285	0.005	1.622
10	1.378	0.976	0.402	29.17	0.314	0.088	0.976	0.595	0.381	39.04	0.354	0.027	0.595	0.447	0.148	24.87	0.139	0.009	0.931
11	1.289	0.904	0.385	29.87	0.327	0.058	0.904	0.555	0.349	38.61	0.323	0.026	0.555	0.411	0.144	25.95	0.136	0.008	0.878
12	2.794	2.009	0.785	28.10	0.658	0.127	2.009	1.326	0.683	34.00	0.665	0.018	1.326	1.01	0.316	23.83	0.311	0.005	1.784
13	3.631	2.614	1.017	28.01	0.749	0.268	2.614	1.752	0.862	32.98	0.838	0.024	1.752	1.452	0.3	17.12	0.295	0.005	2.179
14	2.051	1.456	0.595	29.01	0.471	0.124	1.456	0.917	0.539	37.02	0.518	0.021	0.917	0.688	0.229	24.97	0.225	0.004	1.363

APPENDIX I

15	1.865	1.32	0.545	29.22	0.513	0.032	1.32	0.825	0.495	37.50	0.476	0.019	0.825	0.62	0.205	24.85	0.202	0.003	1.245
TOTAL	**30.435**	**21.71**	**8.725**	**28.67**	**6.919**	**1.806**	**21.71**	**13.879**	**7.831**	**36.07**	**7.416**	**0.415**	**13.879**	**10.58**	**3.299**	**23.77**	**3.215**	**0.084**	**19.855**
MEAN	**2.029**	**1.447**	**0.582**		**0.461**	**0.120**	**1.447**	**0.925**	**0.522**		**0.494**	**0.028**	**0.925**	**0.705**	**0.220**		**0.214**	**0.006**	**1.324**
STAND. D	**0.68**	**0.49**	**0.19**		**0.137**	**0.067**	**0.49**	**0.35**	**0.15**		**0.150**	**0.010**	**0.35**	**0.29**	**0.06**		**0.07**	**0.00**	**0.39**

CR= Coarse Residue; SR= Sawdust

e Input and output volumes of wood and residue at Company C for *Pterygota macrocarpa*

	BANDMILL						EDGER					
Log. No.	**Input vol. (m3)**	Bandmill board vol. (m3)	Residue vol.(m3)	Residue %	CR(m3)	SR(m3)	Input Board vol. (m3)	Edged board vol.(m3)	Residue vol. (m3)	Residue %	CR(m3)	SR(m3)
1	**3.23**	2.599	0.627	19.44	0.434	0.193	2.599	2.033	0.57	21.78	0.541	0.025
2	**2.7**	1.84	0.858	31.80	0.657	0.201	1.84	1.275	0.57	30.71	0.541	0.024
3	**1.34**	0.954	0.388	28.91	0.245	0.143	0.954	0.389	0.57	59.22	0.321	0.244
4	**0.95**	0.634	0.318	33.40	0.224	0.094	0.634	0.07	0.56	88.96	0.216	0.348
5	**1.34**	0.954	0.388	28.91	0.245	0.143	0.954	0.389	0.57	59.22	0.321	0.244
6	**2.67**	1.946	0.728	27.23	0.57	0.158	1.946	1.38	0.57	29.09	0.532	0.034
7	**2.7**	1.84	0.858	31.80	0.657	0.201	1.84	1.275	0.57	30.71	0.541	0.024
8	**2.67**	1.946	0.728	27.23	0.57	0.158	1.946	1.38	0.57	29.09	0.532	0.034
9	**2.85**	2.16	0.685	24.08	0.348	0.337	2.16	1.646	0.51	23.80	0.48	0.034
10	**2.15**	1.805	0.349	16.20	0.266	0.083	1.805	1.275	0.53	29.36	0.495	0.035
11	**2.07**	1.483	0.591	28.50	0.326	0.265	1.483	1.124	0.36	24.21	0.324	0.035
12	**1.47**	1.16	0.313	21.25	0.243	0.07	1.16	0.4	0.76	65.52	0.72	0.04
13	**1.92**	1.372	0.551	28.65	0.337	0.214	1.372	0.84	0.53	38.78	0.488	0.044

APPENDIX I

14	**2.68**	2.022	0.656	24.50	0.425	0.231	2.022	0.827	1.2	59.10	1.182	0.013
15	**2.37**	1.965	0.409	17.23	0.219	0.19	1.965	1.443	0.52	26.56	0.488	0.034
TOTAL	**33.1**	**24.68**	**8.447**	**25.50**	**5.8**	**2.68**	**24.7**	**16**	**8.9**	**36.20**	**7.7**	**1.21**
MEAN	2.208	1.645	0.563		0.384	0.179	1.645	1.050	0.596		0.515	0.081
STAND. D	0.67	0.54	0.19	0.16	0.07	0.54	0.55	0.18	0.22	0.11		

TRIMMER

Input

edged board (m3)	trimmed lumber (m3)	Residue vol. (m3)	Residue %	CR(m3)	SR(m3)	**Total Residue vol. (m3)**
2.033	1.773	0.260	12.79	0.252	0.008	**1.453**
1.275	1.014	0.261	20.47	0.253	0.008	**1.684**
0.389	0.189	0.200	51.41	0.192	0.008	**1.153**
0.07	0.013	0.057	81.43	0.049	0.008	**0.939**
0.389	0.189	0.200	51.41	0.192	0.008	**1.153**

1.38	0.992	0.388	28.12	0.38	0.008	**1.682**
1.275	1.014	0.261	20.47	0.253	0.008	**1.684**
1.38	0.992	0.388	28.12	0.377	0.011	**1.682**
1.646	1.294	0.352	21.39	0.348	0.004	**1.551**
1.275	1.002	0.273	21.41	0.262	0.011	**1.152**
1.124	0.868	0.256	22.78	0.251	0.005	**1.206**
0.4	0.148	0.252	63.00	0.25	0.002	**1.325**
0.84	0.627	0.213	25.36	0.201	0.012	**1.296**
0.827	0.576	0.251	30.35	0.24	0.011	**2.102**
1.443	1.179	0.264	18.30	0.26	0.004	**1.195**
15.7	**12**	**3.876**	**24.62**	**3.76**	**0.116**	**1.417**
1.050	0.791	0.258		0.251	0.008	1.417
0.55	0.49	0.08		0.08	0.00	0.31

CR= Coarse Residue; SR= Sawdust **f Input and output volumes of wood and residue at Company C for *Entandrophragma angolense***

	BANDMILL							**EDGER**						**TRIMMER**					
log no.	Input log vol.(m3)	**BM boards vol.(m3)**	Residue vol.	% Residue	CR (m3)	SR (m3)	Input BM boards(m3)	**Edged boards vol.(m3)**	Residue vol.	% Residue	CR (M3)	SR (M3)	Input edged board	**Trimmed lumber(m3)**	Residue vol.(m3)	% Residue	CR (m3)	SR (m3)	Total Residue (m3)
1	1.145	0.859	0.286	24.98	0.191	0.095	0.859	0.554	0.305	35.51	0.287	0.018	0.554	0.451	0.103	18.59	0.096	0.007	0.694
2	0.831	0.613	0.218	26.23	0.117	0.101	0.613	0.392	0.221	36.05	0.198	0.023	0.392	0.315	0.077	19.64	0.072	0.005	0.516
3	1.232	0.914	0.318	25.81	0.211	0.107	0.914	0.59	0.324	35.45	0.292	0.032	0.59	0.481	0.109	18.47	0.102	0.007	0.751
4	2.437	1.876	0.561	23.02	0.354	0.207	1.876	1.261	0.615	32.78	0.574	0.041	1.261	1.073	0.188	14.91	0.181	0.007	1.364

APPENDIX I

5	1.98	1.505	0.475	23.99	0.383	0.092	1.505	0.997	0.508	33.75	0.491	0.017	0.997	0.837	0.16	16.05	0.154	0.006	1.143
6	2.328	1.862	0.466	20.02	0.394	0.072	1.862	1.24	0.622	33.40	0.600	0.022	1.24	1.116	0.124	10.00	0.116	0.008	1.212
7	1.542	1.163	0.379	24.58	0.362	0.017	1.163	0.758	0.405	34.82	0.374	0.031	0.758	0.626	0.132	17.41	0.125	0.007	0.916
8	2.643	2.051	0.592	22.40	0.502	0.09	2.051	1.384	0.667	32.52	0.648	0.019	1.384	1.187	0.197	14.23	0.193	0.004	1.456
9	2.564	1.99	0.574	22.39	0.45	0.124	1.99	1.34	0.65	32.66	0.625	0.025	1.34	1.146	0.194	14.48	0.187	0.007	1.418
10	2.511	1.933	0.578	23.02	0.474	0.104	1.933	1.305	0.628	32.49	0.610	0.018	1.305	1.109	0.196	15.02	0.19	0.006	1.402
11	2.162	1.645	0.517	23.91	0.396	0.121	1.645	1.094	0.551	33.50	0.528	0.023	1.094	0.924	0.17	15.54	0.162	0.008	1.238
12	2.904	2.265	0.639	22.00	0.479	0.16	2.265	1.631	0.634	27.99	0.609	0.025	1.631	1.459	0.172	10.55	0.165	0.007	1.445
13	3.102	2.637	0.465	14.99	0.332	0.133	2.637	1.859	0.778	29.50	0.760	0.018	1.859	1.692	0.167	8.98	0.16	0.007	1.41
14	1.907	1.447	0.46	24.12	0.369	0.091	1.447	0.958	0.489	33.79	0.470	0.019	0.958	0.8	0.158	16.49	0.152	0.006	1.107
15	1.711	1.292	0.419	24.49	0.31	0.109	1.292	0.847	0.445	34.44	0.424	0.021	0.847	0.706	0.141	16.65	0.134	0.007	1.005
TOTAL	30.999	24.052	6.947	22.41	5.324	1.623	24.052	16.21	7.842	32.60	7.490	0.352	16.21	13.922	2.288	14.11	2.189	0.099	17.077
MEAN	2.067	1.603	0.463		0.355	0.108	1.603	1.081	0.523		0.499	0.023	1.081	0.928	0.153		0.146	0.007	1.138
STAND. D	0.67	0.56	0.12		0.11	0.04	0.56	0.41	0.16		0.16	0.01	0.41	0.38	0.04		0.04	0.00	0.30

CR= Coarse Residue; SR= Sawdust

g Input and output volumes of wood and residue at Company D for *Pterygota macrocarpa*

BANDMILL **EDGER** **TRIMMER**

APPENDIX I

Log. No.		**Input vol. (m3)**	Bandmill board vol. (m3)	Residue vol.(m3)	Residue %	CR(m3)	SR(m3)		Input Board vol. (m3)	Edged board vol.(m3)	Residue vol. (m3)	Residue %	CR(m3)	SR(m3)		Input edged board (m3)	trimmed lumber (m3)	Residue vol. (m3)	Residue %	CR(m3)	SR(m3)	**Total Residue vol. (m3)**
1		**1.923**	1.372	0.551	28.65	0.336	0.215		1.372	0.941	0.431	31.41	0.4	0.031		0.941	0.639	0.302	32.09	0.3	0.002	1.284
2		**2.074**	1.483	0.591	28.50	0.36	0.231		1.483	1.124	0.359	24.21	0.324	0.035		1.124	0.868	0.256	22.78	0.25	0.006	1.206
3		**1.93**	1.352	0.578	29.95	0.373	0.205		1.352	0.84	0.512	37.87	0.488	0.024		0.84	0.627	0.213	25.36	0.21	0.003	1.303
4		**1.952**	1.417	0.535	27.41	0.455	0.08		1.417	0.705	0.712	50.25	0.679	0.033		0.705	0.669	0.036	5.11	0.033	0.003	1.283
5		**1.372**	1.077	0.295	21.50	0.2	0.095		1.077	0.907	0.17	15.78	0.145	0.025		0.907	0.743	0.164	18.08	0.162	0.002	0.629
6		**2.324**	1.779	0.545	23.45	0.445	0.1		1.779	1.323	0.456	25.63	0.421	0.035		1.323	0.911	0.412	31.14	0.41	0.002	1.413
7		**2.374**	1.965	0.409	17.23	0.22	0.189		1.965	1.443	0.522	26.56	0.488	0.034		1.443	1.179	0.264	18.30	0.26	0.004	1.195
8		**1.952**	1.417	0.535	27.41	0.352	0.183		1.417	0.705	0.712	50.25	0.704	0.008		0.705	0.669	0.036	5.11	0.03	0.006	1.283
9		**1.923**	1.371	0.552	28.71	0.336	0.216		1.372	0.941	0.431	31.41	0.4	0.031		0.941	0.639	0.302	32.09	0.3	0.002	1.285
10		**2.445**	1.715	0.73	29.86	0.466	0.264		1.715	1.165	0.55	32.07	0.51	0.04		1.165	0.863	0.302	25.92	0.3	0.002	1.582
11		**2.069**	1.685	0.384	18.56	0.275	0.109		1.685	1.277	0.408	24.21	0.386	0.022		1.277	1.057	0.22	17.23	0.213	0.007	1.012
12		**1.456**	1.273	0.183	12.57	0.157	0.026		1.273	0.868	0.405	31.81	0.38	0.025		0.868	0.648	0.22	25.35	0.213	0.007	0.808
13		**0.621**	0.502	0.119	19.16	0.11	0.009		0.502	0.268	0.234	46.61	0.214	0.02		0.268	0.042	0.226	84.33	0.22	0.006	0.579
14		**2.398**	1.955	0.443	18.47	0.278	0.165		1.955	1.541	0.414	21.18	0.39	0.024		1.541	1.332	0.209	13.56	0.201	0.008	1.066
15		**1.528**	1.205	0.323	21.14	0.234	0.089		1.205	0.803	0.402	33.36	0.381	0.021		0.803	0.565	0.238	29.64	0.23	0.008	0.963
	TOTAL	**28.341**	**21.568**	**6.773**	**23.90**	**4.597**	**2.176**	**TOTAL**	**21.569**	**14.851**	**6.718**	**31.15**	**6.31**	**0.408**	**TOTAL**	**14.851**	**11.451**	**3.4**	**22.89**	**3.332**	**0.068**	**16.891**
	MEAN	1.889	1.438	0.452		0.306	0.145	**MEAN**	1.438	0.990	0.448		0.421	0.027	**MEAN**	0.990	0.763	0.227		0.222	0.005	1.126

APPENDIX I

STAND. D	0.48	0.37	0.17	0.11	0.08	**STAND. D**	0.37	0.33	0.15	0.15	0.01	**STAND. D**	0.33	0.30	0.10	0.10	0.00	0.28

CR= Coarse Residue; SR= Sawdust

h Input and output volumes of wood and residue at Company D for *Entandrophragma angolense*

	BANDMILL						EDGER						TRIMMER						
log no.	Input log vol.(m3)	**BM boards vol.(m3)**	Residue vol.	% Residue	CR (m3)	SR (m3)	Input BM boards(m3)	**Edged boards vol.(m3)**	Residue vol.	% Residue	CR (M3)	SR (M3)	Input edged board	**Trimmed lumber(m3)**	Residue vol.(m3)	% Residue	CR (m3)	SR (m3)	Total Residue (m3)
1	1.257	0.927	0.33	26.25	0.228	0.102	0.927	0.342	0.585	63.11	0.567	0.018	0.342	0.136	0.206	60.23	0.199	0.007	1.121
2	1.456	1.273	0.183	12.57	0.158	0.025	1.273	0.868	0.405	31.81	0.38	0.025	0.868	0.648	0.22	25.35	0.213	0.007	0.808
3	1.257	0.999	0.258	20.53	0.228	0.03	0.999	0.545	0.454	45.45	0.42	0.034	0.545	0.343	0.202	37.06	0.197	0.005	0.914
4	1.528	1.205	0.323	21.14	0.254	0.069	1.205	0.803	0.402	33.36	0.381	0.021	0.803	0.565	0.238	29.64	0.23	0.008	0.963
5	2.398	1.955	0.443	18.47	0.378	0.065	1.955	1.541	0.414	21.18	0.39	0.024	1.541	1.333	0.208	13.50	0.201	0.007	1.065
6	2.076	1.578	0.498	23.99	0.399	0.099	1.578	1.046	0.532	33.71	0.506	0.026	1.046	0.879	0.167	15.97	0.163	0.004	1.197
7	1.242	0.922	0.32	25.76	0.295	0.025	0.922	0.597	0.325	35.25	0.300	0.025	0.597	0.519	0.078	13.07	0.071	0.007	0.723
8	2.788	2.161	0.627	22.49	0.426	0.201	2.161	1.461	0.7	32.39	0.681	0.019	1.461	1.264	0.197	13.48	0.194	0.003	1.524
9	1.168	0.864	0.304	26.03	0.106	0.198	0.864	0.558	0.306	35.42	0.285	0.021	0.558	0.458	0.1	17.92	0.091	0.009	0.71
10	1.126	0.834	0.292	25.93	0.204	0.088	0.834	0.53	0.304	36.45	0.282	0.022	0.53	0.435	0.095	17.92	0.089	0.006	0.691

APPENDIX I

11	1.133	0.872	0.261	23.04	0.156	0.105		0.872	0.662	0.21	24.08	0.192	0.018		0.662	0.596	0.066	9.97	0.06	0.006	0.537
12	1.479	1.109	0.37	25.02	0.195	0.175		1.109	0.722	0.387	34.90	0.354	0.033		0.722	0.597	0.125	17.31	0.117	0.008	0.882
13	0.872	0.641	0.231	26.49	0.134	0.097		0.641	0.41	0.231	36.04	0.190	0.041		0.41	0.332	0.078	19.02	0.072	0.006	0.54
14	2.076	1.578	0.498	23.99	0.365	0.133		1.578	1.046	0.532	33.71	0.440	0.092		1.046	0.879	0.167	15.97	0.16	0.007	1.197
15	1.242	0.922	0.32	25.76	0.195	0.125		0.922	0.596	0.326	35.36	0.287	0.039		0.596	0.488	0.108	18.12	0.1	0.008	0.754
TOTA	23.098	17.84	5.258	22.76	3.721	1.537	**TOTAL**	17.84	11.727	6.113	34.27	5.655	0.458	**TOTAL**	11.727	9.472	2.255	19.23	2.157	0.098	13.626
MEAN	1.54	1.19	0.35		0.25	0.10	**MEAN**	1.189	0.782	0.408		0.377	0.031	**MEAN**	0.782	0.631	0.150		0.144	0.007	0.908
STAND. D.	0.54	0.44	0.12		0.10	0.06	**STAND. D**	0.44	0.36	0.14		0.13	0.02	**STAND. D**	0.36	0.33	0.06		0.06	0.00	0.27

CR= Coarse Residue; SR= Sawdust

APPENDIX II: THE DESCRIPTIVE TABLE FOR PRODUCTION PROCESS

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
T. scleroxylon coarse residue	Bandmill	30	.19983	.166168	.030338	.13779	.26188	.050	.956
	Edger	30	.42900	.309314	.056473	.31350	.54450	.095	1.473
	Trimmer	30	.18377	.101359	.018506	.14592	.22161	.043	.367
	Total	90	.27087	.237080	.024990	.22121	.32052	.043	1.473
T. scleroxylon sawdust residue	Bandmill	30	.12207	.081163	.014818	.09176	.15237	.034	.471
	Edger	30	.01970	.010616	.001938	.01574	.02366	.007	.050
	Trimmer	30	.00313	.001137	.000208	.00271	.00356	.002	.006
	Total	90	.04830	.070578	.007440	.03352	.06308	.002	.471
C. gabunensis coarse residue	Bandmill	30	.39757	.131903	.024082	.34831	.44682	.193	.749
	Edger	30	.44207	.142872	.026085	.38872	.49542	.186	.838
	Trimmer	30	.18647	.064296	.011739	.16246	.21048	.076	.311
	Total	90	.34203	.161980	.017074	.30811	.37596	.076	.838
C. gabunensis sawdust residue	Bandmill	30	.11480	.061317	.011195	.09190	.13770	.027	.268
	Edger	30	.02533	.007779	.001420	.02243	.02824	.018	.054
	Trimmer	30	.00567	.001605	.000293	.00507	.00627	.003	.009
	Total	90	.04860	.059386	.006260	.03616	.06104	.003	.268
P. macrocarpa coarse residue	Bandmill	30	.34543	.139548	.025478	.29333	.39754	.110	.657
	Edger	30	.46773	.191054	.034882	.39639	.53907	.145	1.182
	Trimmer	30	.46773	.191054	.034882	.39639	.53907	.145	1.182
	Total	90	.42697	.183014	.019291	.38864	.46530	.110	1.182
P. macrocarpa sawdust	Bandmill	30	.16190	.074876	.013670	.13394	.18986	.009	.337
	Edger	30	.05400	.078182	.014274	.02481	.08319	.008	.348
	Trimmer	30	.00613	.003082	.000563	.00498	.00728	.002	.012
	Total	90	.07401	.090074	.009495	.05515	.09288	.002	.348
E. angolense coarse residue	Bandmill	30	.30147	.117811	.021509	.25748	.34546	.106	.502
	Edger	30	.43817	.156743	.028617	.37964	.49670	.190	.760
	Trimmer	30	.14487	.049067	.008958	.12654	.16319	.060	.230
	Total	90	.29483	.166833	.017586	.25989	.32978	.060	.760
E. angolense sawdust residue	Bandmill	30	.10533	.049150	.008973	.08698	.12369	.017	.207
	Edger	30	.02700	.014142	.002582	.02172	.03228	.017	.092
	Trimmer	30	.00657	.001331	.000243	.00607	.00706	.003	.009

	Total	90	.04630	.051820	.005462	.03545	.05715	.003	.207

APPENDIX III **MULTIPLE COMPARISONS (**TUKEY POST-HOC TEST)

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Machine	(J) Machine	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
T. scleroxylon coarse residue	Bandmill	Edger	-.229167*	.054480	.000	-.35907	-.09926
		Trimmer	.016067	.054480	.953	-.11384	.14597
	Edger	Bandmill	.229167*	.054480	.000	.09926	.35907
		Trimmer	.245233*	.054480	.000	.11533	.37514
	Trimmer	Bandmill	-.016067	.054480	.953	-.14597	.11384
		Edger	-.245233*	.054480	.000	-.37514	-.11533
T. scleroxylon sawdust residue	Bandmill	Edger	.102367*	.012203	.000	.07327	.13147
		Trimmer	.118933*	.012203	.000	.08983	.14803
	Edger	Bandmill	-.102367*	.012203	.000	-.13147	-.07327
		Trimmer	.016567	.012203	.368	-.01253	.04567
	Trimmer	Bandmill	-.118933*	.012203	.000	-.14803	-.08983
		Edger	-.016567	.012203	.368	-.04567	.01253
C. gabunensis coarse residue	Bandmill	Edger	-.044500	.030530	.316	-.11730	.02830
		Trimmer	.211100*	.030530	.000	.13830	.28390
	Edger	Bandmill	.044500	.030530	.316	-.02830	.11730
		Trimmer	.255600*	.030530	.000	.18280	.32840
	Trimmer	Bandmill	-.211100*	.030530	.000	-.28390	-.13830
		Edger	-.255600*	.030530	.000	-.32840	-.18280
C. gabunensis sawdust residue	Bandmill	Edger	.089467*	.009217	.000	.06749	.11144
		Trimmer	.109133*	.009217	.000	.08716	.13111
	Edger	Bandmill	-.089467*	.009217	.000	-.11144	-.06749
		Trimmer	.019667	.009217	.089	-.00231	.04164
	Trimmer	Bandmill	-.109133*	.009217	.000	-.13111	-.08716
		Edger	-.019667	.009217	.089	-.04164	.00231
P. macrocarpa coarse residue	Bandmill	Edger	-.122300*	.045333	.023	-.23039	-.01421
		Trimmer	-.122300*	.045333	.023	-.23039	-.01421
	Edger	Bandmill	.122300*	.045333	.023	.01421	.23039
		Trimmer	.000000	.045333	1.000	-.10809	.10809

	Trimmer	Bandmill	.122300*	.045333	.023	.01421	.23039
		Edger	.000000	.045333	1.000	-.10809	.10809
P. macrocarpa sawdust	Bandmill	Edger	.107900*	.016144	.000	.06940	.14640
		Trimmer	.155767*	.016144	.000	.11727	.19426
	Edger	Bandmill	-.107900*	.016144	.000	-.14640	-.06940
		Trimmer	.047867*	.016144	.011	.00937	.08636
	Trimmer	Bandmill	-.155767*	.016144	.000	-.19426	-.11727
		Edger	-.047867*	.016144	.011	-.08636	-.00937
E. angolense coarse residue	Bandmill	Edger	-.136700*	.030131	.000	-.20855	-.06485
		Trimmer	.156600*	.030131	.000	.08475	.22845
	Edger	Bandmill	.136700*	.030131	.000	.06485	.20855
		Trimmer	.293300*	.030131	.000	.22145	.36515
	Trimmer	Bandmill	-.156600*	.030131	.000	-.22845	-.08475
		Edger	-.293300*	.030131	.000	-.36515	-.22145
E. angolense sawdust residue	Bandmill	Edger	.078333*	.007627	.000	.06015	.09652
		Trimmer	.098767*	.007627	.000	.08058	.11695
	Edger	Bandmill	-.078333*	.007627	.000	-.09652	-.06015
		Trimmer	.020433*	.007627	.024	.00225	.03862
	Trimmer	Bandmill	-.098767*	.007627	.000	-.11695	-.08058
		Edger	-.020433*	.007627	.024	-.03862	-.00225
*. The mean difference is significant at the 0.05 level.							

a : QUESTIONNAIRE TO THE FINANCE OFFICERS OF THE SAWMILLS

This is a PhD. Thesis Project "Wood Residue Generation and Utilization; the Technical, Economic and Environmental Mix for some selected Sawmills in Brong Ahafo and Ashanti Region, Ghana" by SYLVIA ADU (MRS.) of Kwame Nkrumah University of Science and Technology. Please you are being asked to provide information for the following questions. I wish to give you the assurance that any information provided shall be used purely for academic purposes. Your anonymity and confidentiality are assured.

1. Name of Company………………………………………………………………………. 2. Status in the Company……………………………………………………….

3. How long have you been working here?
    a. Less than three (3) years
    b. Between three (3) and six (6) years
    c. Between six (6) and ten (10) years
    d. More than ten (10) years
4. How do you obtain your raw material?
    a. Own concession
    b. Buy from timber contractors
5. How much would your company buy a quality log per unit volume (per cubic metre)?

Species	Price per cubic metre (GHC)
Cylicodiscus gabunensis (Denya)	
Entandrophragma angolense (Edinam)	
Triplochiton scleroxylon (Wawa)	
Pterygota macrocarpa (Koto)	

6. How much did your company sell a unit volume of lumber?

Species	FAS - Price per cubic metre (GHC)	No.1 Common - Price per cubic metre (GHC)	No. 2 Common - Price per cubic metre (GHC)
Cylicodiscus gabunensis			
Entandrophragma angolense			
Triplochiton scleroxylon			
Pterygota macrocarpa			

7. How many workers are associated with the sawmill section?
    a. Skilled:…………………………
    b. Semi-skilled:……………………
    c. Unskilled:………………………

8. How many shifts do you run in a day?

APPENDIX IV

   a. One:……………………..
   b. Two:……………………..
   c. Three:……………………

9. What is the average monthly salary of each worker?
   a. Skilled:……………………
   b. Semi-skilled:……………….
   c. Unskilled:………………….
10. What is the estimated cost of repair and maintenance of sawmilling machines per month?
    a. Sep. 2012:…………………………
    b. Oct. 2012:…………………………
11. How much Electricity was consumed in Sep. 2012 & Oct. 2012?
    a. Sep. 2012:…………………………
    b. Oct. 2012:…………………………
12. How much did you spend as fixed cost (overheads) per month?
    a. Sep. 2012:…………………………
    b. Oct. 2012:…………………………
13. How much did you spend in transporting logs from the forest to the mill?
    a. Sep. 2012:…………………………
    b. Oct. 2012:…………………………
14. How much did you spend on sawdust carting from the mill to the dumping site?
    a. Sep. 2012:………………………….
    b. Oct. 2012:…………………………
15. Do you have any market strategy for selling wood products from wood residues?
    Yes: ………….
    No: ………….
    If Yes describe briefly.

………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………

16. Do you have problems with marketing products from wood residue?
    Yes:…………
    No: …………
    If Yes, elaborate on some of the major problems

………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………

Thank you very much.

b : QUESTIONNAIRE TO THE MARKETING MANAGERS OF THE SAWMILLS

This is a PhD. Thesis Project "Wood Residue Generation and Utilization; the Technical, Economic and Environmental Mix for some selected Sawmills in Brong Ahafo and Ashanti Region, Ghana" by SYLVIA ADU (MRS.) of Kwame Nkrumah University of Science and Technology. Please you are being asked to provide information for the following questions. I wish to give you the assurance that any information provided shall be used purely for academic purposes. Your anonymity and confidentiality are assured.

1. Name of Company………………………………………………………… 2. Status in the Company…………………………………………………………….
3. How long have you been working here?
   a. Less than three (3) years
   b. Between three (3) and six (6) years
   c. Between six (6) and ten (10) years
   d. More than ten (10) years
4. How do you obtain your raw material?
   a. Own concession
   b. Buy from timber contractors
5. How much would your company buy a quality log per unit volume (per cubic metre)?

Species	Price per cubic metre (GHC)
Cylicodiscus gabunensis (Denya),	
Entandrophragma angolense (Edinam),	
Triplochiton scleroxylon (Wawa)	
Pterygota macrocarpa (Koto).	

6. How much did your company sell a unit volume of lumber?

APPENDIX IV

Species	FAS - Price per cubic metre (GHC)	No.1 Common - Price per cubic metre (GHC)	No. 2 Common - Price per cubic metre (GHC)
Cylicodiscus gabunensis			
Entandrophragma angolense			
Triplochiton scleroxylon			
Pterygota macrocarpa			

7. How much lumber volume was produced in a month?

Species	Volume (m^3) - Sep. 2012	Volume (m^3) - Oct. 2012
Cylicodiscus gabunensis		
Entandrophragma angolense		
Triplochiton scleroxylon		
Pterygota macrocarpa		

8. How many shifts do you run in a day?
    a. One:……………………..
    b. Two:……………………..
    c. Three:……………………
9. Do you have any market strategy for selling wood products from wood residues?
   Yes: ………….
   No: ………….
   If Yes describe briefly

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

10. Do you have problems with marketing products from wood residue?
    Yes:…………
    No: …………
    If Yes, elaborate on some of the major problems

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

Thank you very much.

c : QUESTIONNAIRE TO THE PRODUCTION MANAGERS OF THE SAWMILLS

This is a PhD. Thesis Project "Wood Residue Generation and Utilization; the Technical, Economic and Environmental Mix for some selected Sawmills in Brong Ahafo and Ashanti Region, Ghana" by SYLVIA ADU (MRS.) of Kwame Nkrumah University of Science and Technology. Please you are being asked to provide information for the following questions. I wish to give you the assurance that any information provided shall be used purely for academic purposes. Your anonymity and confidentiality are assured.

1. Name of Company………………………………………………………………… 2. Status in the Company……………………………………………………….

3. How long have you been working here?
   a. Less than three (3) years
   b. Between three (3) and six (6) years
   c. Between six (6) and ten (10) years
   d. More than ten (10) years

APPENDIX IV

4. How do you obtain your raw material?
   a. Own concession
   b. Buy from timber contractors

5. How much do your company buy a quality log per unit volume (per cubic metre)?

Species	Price per cubic metre (GHC)
Cylicodiscus gabunensis (Denya),	
Entandrophragma angolense (Edinam),	
Triplochiton scleroxylon (Wawa)	
Pterygota macrocarpa (Koto).	

6. How long do logs stay at the log yard before processing?
   a. Up to two weeks. (   )
   b. Two weeks to one month. (   )
   c. More than one month. (   )
7. Why are some logs left at the log yard for a long period?
……
……
……
8. What kind of log preparation is done in the log yard and how do they affect the amount of wood residue produced?
……
……
……
9. What type of defects in the logs affect the amount of wood residue produced?
....
....
....

10. What efforts do you make to reduce wastage at the sawmill?
....
....

....
.

11. How are these residues disposed off or utilized?

Type of Residue	Volume (m^3)	Recovered (%)	Recovered (m^3)	To Furnace (%)	Sold (%)	Discarded (%)
Slabs						
Edgings						
Trimmings						
Sawdust						

12. How much does it cost to transport a truck load of wood residue to the dumping site? GHC………………..

13. What suggestions do you have on the utilization of wood residue?
....
....
....
....
.

14. Do you have any market strategy for selling wood products from wood residues?
Yes: ………….
No: ………….
If Yes describe briefly.
……………………………………………………………………………………………
…
……………………………………………………………………………………………
…

15. Do you have problems with marketing products from wood residue?
Yes:…………
No: …………
If Yes, elaborate on some of the major problems
……………………………………………………………………………………………
…
……………………………………………………………………………………………
…

16. What is your opinion on the integration of sawmill operation with small-scale industrial activities such as charcoal production and carpentry
....
.
....
.

17. What is your opinion about co-generation of energy in the sawmill using wood residue?

APPENDIX IV

....
.
....
.

18. Have you ever attended any Conference, Workshop or Seminar on the utilization of wood residue?

Yes: …………… No: ………………

19. How do you dispose off wood residues for which you do not have any use at the moment?
    a. Burn

b. Pack on factory floor
c. Deposit in near-by water bodies
d. Sell to bakers or distillers

20. Do you know of any environmental effects of the ways you dispose of your wood residues?
Yes: ……….. No: ………… Explain briefly.
……………………………………………………………………………………………………
……………………………………………………………………………………………………
.

21. What is the mills policy on waste disposal?
……………………………………………………………………………………………………
……………………………………………………………………………………………………

22. How old are the machines used?

Machines	Years in operation
Bandmill	
Edger	
Trimmer	

23. How much log volume was processed in a month?

Species	Volume (m^3) - Sep. 2012	Volume (m^3) - Oct. 2012
Cylicodiscus gabunensis		
Entandrophragma angolense		
Triplochiton scleroxylon		
Pterygota macrocarpa		

24. How much lumber volume was produced in a month?

Species	Volume (m^3) - Sep. 2012	Volume (m^3) - Oct. 2012
Cylicodiscus gabunensis		
Entandrophragma angolense		
Triplochiton scleroxylon		
Pterygota macrocarpa		

25. How much did your company sell a unit volume of lumber?

Species	FAS - Price per cubic metre (GHC)	No.1 Common - Price per cubic metre (GHC)	No. 2 Common - Price per cubic metre (GHC)
Cylicodiscus gabunensis			
Entandrophragma angolense			
Triplochiton scleroxylon			

Pterygota macrocarpa			

26. How many workers are associated with the sawmill section?
    a. Skilled:…………………………
    b. Semi-skilled:……………………
    c. Unskilled:………………………
27. How many shifts do you run in a day?
    a. One:……………………..
    b. Two:……………………..
    c. Three:……………………
28. What is the average monthly salary of each worker?
    a. Skilled:……………………
    b. Semi-skilled:……………….
    c. Unskilled:………………….
29. Please, provide any other information in relation to wood residue and sawmilling operations cost
    ………………………………………………………………………………………………
    ………………………………………………………………………………………………
………………………………………………………………………………………………

Thank you very much.

APPENDIX Va Transportation Cost of Logs to Company A

Volume of logs per month = 1,100.000m^3
Volume of logs used during the study = 69.603m^3
Average volume of logs per trip =22.000m^3
Average number of trips by tractors per month = 50
Average fuel consumed per trip = 380.00 Ghana cedis
Average fuel consumed per month = 19,000.00 Ghana cedis
Average fuel for transporting the logs for the research $= \frac{69.603}{1,100.000} \times 19,000.00$
= 1,202.00 Ghana cedis

APPENDIX Vb Transportation Cost of Logs to Company D

Volume of logs per month = 950.000m^3
Volume of logs used during the study = 51.439m^3
Average volume of logs per trip =17.000m^3
Average number of trips by tractors per month = 56
Average fuel consumed per trip = 280.00 Ghana cedis
Average fuel consumed per month = 15,680.00 Ghana cedis

Average fuel for transporting the logs for the research $= \frac{51.439}{950.00} \times 15,680.00$

= 849.00 Ghana cedis

APPENDIX VI Cost of Logs and Export Lumber during the study (2012)

<u>Log Prices in Ghana cedis per cubic metres</u>

Species	Price Range	Average Price
Cylicodiscus gabunensis (Denya)	140 – 160	150
Entandrophragma angolense (Edinam)	150 – 250	200
Pterygota macrocarpa (Koto)	120 – 140	130
Triplochiton scleroxylon (Wawa)	100 – 120	110

(Obtained from Questionnaires and Interviews)

Company A – Wawa – 46.670×110 = 5,133.70
- Denya – 22.933×150 = 3,439.99

Total **69.603** **8,573.69**

Company D – Koto – 28.341×130 = 3,684.33
- Edinam - 23.098×200 = 4,619.60

Total **51.439** **8,303.93**

<u>Lumber Prices per cubic metre</u>

Species	Price Range (Euro)	Average Price (Euro)	Average Price (Ghana cedis)
Cylicodiscus gabunensis (Denya)	450 – 550	500	1,138.30
Entandrophragma angolense (Edinam)	380 – 600	490	1,115.53
Pterygota macrocarpa (Koto)	440 – 520	480	1,092.77
Triplochiton scleroxylon (Wawa)	280 – 360	320	728.51

(Obtained from Questionnaires and Interviews)

The current Forex Bureau rate was about GH¢ 2.2766 to one Euro (March, 2012).

APPENDIX VII Water holding capacity of *Cylicodiscus gabunensis*, *Entandrophragma angolense*, *Triplochiton scleroxylon* and *Pterygota macrocarpa*

Time (hours)	Species	Final mass (wet sample) (g)	Initial mass (dry sample) (g)	Mass of water (g)	Water (%)
1	*E. angolense*	43.13	10.00	33.13	331.30
	T. scleroxylon	73.50	10.00	63.50	635.00
	P. macrocarpa	78.65	10.00	68.65	686.50
	C. gabunensis	44.93	10.00	34.93	349.30
4	*E. angolense*	43.19	10.00	33.19	331.90
	T. scleroxylon	74.99	10.00	64.99	649.90
	P. macrocarpa	80.99	10.00	70.99	709.90
	C. gabunensis	43.71	10.00	33.71	337.10
8	*E. angolense*	50.46	10.00	40.46	404.60
	T. scleroxylon	83.30	10.00	73.30	733.00
	P. macrocarpa	73.28	10.00	63.28	632.80
	C. gabunensis	42.74	10.00	32.74	327.40
12	*E. angolense*	49.93	10.00	39.93	399.30
	T. scleroxylon	75.30	10.00	65.30	653.00
	P. macrocarpa	75.73	10.00	65.73	657.30
	C. gabunensis	44.14	10.00	34.14	341.40

Values are means of triplicate samples (Source: Field Survey, 2012)

APPENDIX VIIIa Decomposition rate of *T. scleroxylon*–Average mass remaining (g)

	Fresh Dump	Dry Dump	Fresh Buried	Dry Buried
WEEK 0	100.00	100.00	100.00	100.00
WEEK 2	122.67	97.54	127.73	99.61
WEEK 4	122.63	96.67	130.17	99.33
WEEK 6	133.78	91.56	144.04	98.49
WEEK 8	136.65	78.24	148.49	83.35
WEEK 10	85.15	72.52	91.12	76.85
WEEK 12	242.01	67.84	152.36	72.36

APPENDIX VIIIb Decomposition rate of *P. macrocarpa*-Average mass remaining(g)

	Fresh Dump	Dry Dump	Fresh Buried	Dry Buried
WEEK 0	100.00	100.00	100.00	100.00
WEEK 2	107.77	98.15	108.36	93.12
WEEK 4	110.04	95.10	108.39	88.38
WEEK 6	137.93	92.74	136.37	87.42
WEEK 8	109.63	68.80	133.17	78.00
WEEK 10	95.83	67.44	85.66	75.61
WEEK 12	386.26	65.23	285.52	70.71

APPENDIX VIIIc Decomposition rate of *E. angolense*- Average mass remaining (g)

	Fresh Dump	Dry Dump	Fresh Buried	Dry Buried
WEEK 0	100.00	100.00	100.00	100.00
WEEK 2	105.29	92.67	122.47	96.35
WEEK 4	114.28	91.97	121.98	94.47
WEEK 6	131.58	90.02	118.89	86.64
WEEK 8	122.58	75.31	114.25	74.41
WEEK 10	85.43	69.05	89.52	72.76
WEEK 12	155.09	65.79	99.56	70.63

APPENDIX VIIId Decomposition rate of *C. gabunensis*-Average mass remaining (g)

	Fresh Dump	Dry Dump	Fresh Buried	Dry Buried
WEEK 0	100.00	100.00	100.00	100.00
WEEK 2	111.76	93.14	109.78	97.16
WEEK 4	109.04	86.97	114.59	95.51
WEEK 6	127.85	80.04	122.84	92.30
WEEK 8	143.13	81.86	109.25	74.26
WEEK 10	95.49	73.03	84.00	71.42
WEEK 12	228.10	69.94	94.19	71.04

Values are means of triplicate samples (Source: Field Survey, 2012)

APPENDIX IX: INTERVIEW CHECKLIST FOR PEOPLE LIVING NEAR DUMPING SITES OF WOOD RESIDUES

This is a PhD. Thesis Project “Wood Residue Generation and Utilization; the Technical, Economic and Environmental Mix for some selected Sawmills in Brong Ahafo and Ashanti Region, Ghana” by SYLVIA ADU (MRS.) of Kwame Nkrumah University of

Science and Technology. Please you are being asked to provide information for the following questions. I wish to give you the assurance that any information provided shall be used purely for academic purposes. Your anonymity and confidentiality are assured.

Interviewer Name……………………………………………………………

Please tick the respondent‟s status.

1. Name of community:…………
2. Sex: M…….. F……
3. Age: 20 – 39 Years…….. 40 – 59Years …... 60 Years and above …….
4. Level of Education: No formal education……. Primary……..
   JHS/MSLC……. SHS/(O/A Level)…………
5. Origin: Native…………….. Migrant…………..
6. Livelihood activity: Charcoal producer………. Charcoal buyer…………….. Petty Trader……….. Production Manager………………………..
7. How long have you been working here? 2 – 4 Years………..
   5 – 7 Years………….. 8 Years and above…………..
8. Do you know about any effects of inhaling sawdust and the smoke from burning sawdust? Yes…………. No…………..
9. If Yes, state three (3) common ones……………………………………
10. Do you know of any means by which these environmental effects could be minimized? Yes……………. No………………………
11. If Yes, what are some of them? State three……………………………
12. Tick any of the under-listed conditions which you normally experience as you do your normal business here.

Types of Health Problems	**Health problems experienced**
Nasal irritation	
Nasal bleeding	
Prolonged cold	
Itching skin	
Cracking skin	
Throat irritation	
Eye irritation	
Chest pain	
Fast heart beat	
Joint pain	

13. Have you ever been interviewed on the environmental situation over here?
    Yes……………….. No………………
14. If Yes, how many times? ………………

Thank you very much.

APPENDIX X Personal information of Respondents affected by sawdust

PERSONAL INFORMATION \ SITES	Company A	Company B	Company C	Company D	Dumping site		%
Sex							
Male	2	2	2	2	3	- 9	55
Female	0	0	0	0	-		45
Age (Years)							
20 – 39	0	0	1	0	0	4	25
40 -59	2	1	1	2	3	3	60
60+	0	1	0	0	0	2	15
Educational level							
No formal education	0	0	0	0	2	7	45
Junior High School/ Middle School Leaving Certificate	1	0	0	1	1	2	25
Senior High School („O"/ „A" Level)	1	2	2	1	0	0	30
Tertiary	0	0	0	0	0	0	0
Origin							
Native	2	2	1	1	0	1	35
Migrant	0	0	1	1	3	8	65
Livelihood							
Charcoal producer	0	0	0	0	2	5	35
Charcoal buyer	0	0	0	0	0	2	10
Petty trader	0	0	0	0	1	2	15
Production Manager	2	2	2	2	0	0	40
Years spent at the place							
2 – 4	0	0	0	0	0	0	0
5 -7	0	0	0	0	1	2	15
8+	2	2	2	2	2	7	85
Any health problems experienced?							
Yes	2	2	2	2	1	2	55
No	0	0	0	0	2	7	45
Any interview on environmental issues before?							
Yes	2	2	2	2	1	1	50
No	0	0	0	0	2	8	50

APPENDIX XI Abstract of Major Publication (Research Article)

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MAXIMIZING WOOD RESIDUE UTILIZATION AND REDUCING ITS PRODUCTION RATE TO COMBAT CLIMATE CHANGE

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Abstract

Wood is a renewable natural resource which can effectively reduce climate change. Wood processing operations generate enormous amount of wood residues which need to be efficiently managed. A lumber yield of about 28- 64% requires maximizing the economic values of wood. The utilization of wood residue which is deemed as a burdensome waste in many timber industries has the potential of lessening the effects of climate change. This has led to the study of issues associated with the generation and management of wood residues. This research was conducted to examine the rate of wood residue production at the various production lines and its utilization in four selected timber industries in the Ashanti and Brong Ahafo regions of Ghana; and their effects on climate change. Four different timber species, *Cylicodiscus gabunensis* (Denya), *Entandrophragma angolense* (Edinam), *Pterygota macrocarpa* (Koto) and *Triplochiton scleroxylon* (Wawa) were studied. The average lumber recovery percentage at the four sawmills was 38.08% with residue forming 61.92% of the total input volume. It was observed that 9.07% of input volume generated sawdust. However about 60% of this sawdust was not utilized but burnt and/or dumped openly, polluting the environment. It is recommended that the sawdust

could be used to manufacture biochar for soil amendment to enhance nurseries, plantations and other agricultural interests.
Keywords: Wood residue utilization, lumber recovery, sawdust, climate change