Environmental life cycle assessment to enhance the sustainability of the timber sector in Ghana

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John Frank Eshun

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Table of contents

List of Tables

List of Figures

Chapter 1. Introduction

Chapter 1: Introduction

Introduction

Ghana is located on the west coast of Africa and has a land area of 23.9 million hectares and a population of about 22 million people. Ecologically, the country is divided into a high – forest zone in the south accounting for about a third of the land area (8 million hectares), a savanna zone (14.7 million hectares) mostly in the north, and a transition zone with woodlands (1.1 million hectares) in between. Estimates of the total area of forests in the country range from 2.72 million hectares to 6.34 million hectares (FAO 2005a).

Forestry and timber industry in Ghana

The timber sector (i.e. forestry and timber industry) is an important industry in Ghana. It provides a significant contribution to Ghana's foreign exchange earnings through wood products export, provides jobs and incomes for numerous local economies and communities (Lebedys 2004, Odoom 2008).

The Ghanaian timber production is associated with an increasing environmental burden in terms of use of resources, and production of emissions and waste (Ghana Gazette 2005). This has raised a serious concern in the region about deforestation, climate change, waste, soil erosion and large scale desertification (TED 1995). Deforestation has claimed an enormous toll through environmental damage, economic deterioration and human misery (TED 1995). The impact of deforestation is widespread, affecting the livelihoods of local people, disrupting important environmental functions and severely disrupting the biological integrity of the original forest ecosystems. The average estimated annual rate of deforestation between 1990 and 2000 was 120,000 hectares and Ghana lost an average of 115,400 hectare per year from 2000 to 2005 (FAO 2005a). For various reasons, such as over-exploitation of timber and the generation of high volume of wood waste, the tropical forest in Ghana has been decreasing rapidly and significantly (TED 1995).

Ghana's quest for sustainable forest management has motivated the country's involvement in a number of environmental agreements (Coleman 1991, Driver 1995 , EPA 1999, FOSA 2001). This concept of sustainable development has been incorporated in the past decade in several policy documents in the Ghanaian timber sector. It is questionable, however, whether these policies and agreements led to significant positive environmental and social changes. These environmental policies, however, are limited in terms of its implementation. There appears to be a gap between sustainability policies and their implementations in the Ghanaian timber sector. It is important to help policy makers and other stakeholders in the timber sector to identify and bridge this sustainability gap.

The state and structure of the timber industry in Ghana

Table 1 shows the state and structure by activity area of the timber industry in Ghana. According to (TEDB 1991), the Ghanaian timber industry falls into three categories of operations namely: primary (logging), secondary (sawmilling, ply milling and veneering) and tertiary (furniture parts, mouldings and others). According to (EPA 1999), the wood processing industries are classified according to their wood consumption capacity into four categories, namely large companies (> 50,000 m^3 per year), medium- large companies (20,000 – 50,000 m^3 per year) and medium – small companies (5,000 – 20,000 m^3 per year) and small companies (< 5,000 m^3 per year).

Table 1.0: Structure by activity area

Activity area	Number of units
Logging	511
Sawmilling	190
Veneering	23
Ply milling	15
Furniture Parts	40

Source: TIDD, Technical report, 2006

Note: Figures are not additive as units may be involved in more than one activity area

According to FPIB (1996), the timber industry has traditionally concentrated on exports, to the neglect of the local market. The major buyer of Ghanaian timber product is the European Union. Ghana earned 170 million euros form volume sales of 451,608 cubic meters of wood products in 2006. Europe accounted for 80 million euros and 167.701 cubic meters, representing 47.05 percent value and 37.13 percent volume for the total wood export for 2006 (TIDD 2006). The countries are Italy, France, Germany, United Kingdom, Belgium, Spain and The Netherlands. Average annual national production of wood products from 2001 to 2005 was estimated at 280,000 m^3 for veneer, 480,000 m^3 for sawn timber and 114,000 m^3 for plywood (TIDD 2006).

Timber industry and their impacts on the environments

Timber industrial activities cause a variety of environmental problems. These environmental problems receive attention through environmental policies aimed at reducing emissions, wastes and at improving conservation of natural resources. For many timber companies, environmental performance in terms of emissions, production of waste and the use of resources is an increasing concern. In recent decade, the concern about the environmental impact associated with timber production has gone beyond compliance to existing legislation because international markets are more demanding environmental sound product. Therefore, it is important from an environmental perspective that Ghana's timber industry products production process is environmental friendly.

The level of environmental impact caused by a timber industry may vary from country to country, and also from production plant to production plant (Esin 2007). This variation may be as a result of the difference in the technology, methods and environmental standards used in the production process. As a result of strict environmental policies in the developed countries, most industries in the developed counties are not able to cope with that environmental standards and therefore find it convenient to relocate or dispose their plants to the developing countries where such environmental standards are very weak. These supposedly new plants/equipments come with its own accompanied environmental problems and such problems obviously have both regionally and globally implications.

Human population growth and global wood demand have historically tracked very closely and will likely do so in the future (Dixon et al. 1994). The FAO (2001), predicts that global consumption of wood will increase by 45% in 2020, and experts are concerned about the additional pressure this will put on the world's forests. This illustrates the large concerns about this industry. Apart from ecological impacts, activities in the timber sector for example sawmills, ply mills veneer companies differently impact on the environment. The most dominant environmental pressures are in their material usage, emissions, energy use and waste production.

In Ghana, transportation of raw materials to the companies and products from the companies is mainly on trucks and this has an environmental impact in a form of emissions. Relevant environmental parameters included, in this particular emissions is carbon dioxide, nitrogen dioxide, sulphur dioxide, hydrocarbons and the environmental effects are the acidification of soil and water and climatic changes among others. Most timber companies produce appreciable quantities of solid waste either as saw dust, bark, ash, or sludge which may cause considerable environmental nuisance, where materials are treated with preservatives which may have health implication (Driver 1995).There has not been any extensive environmental system analysis of the Ghanaian timber industry. Environmental problems at present are not only occurring at the regional scale, but also at the global scale, which poses potential environmental damage in the country. This has been a major concern to governments and other international bodies. The environmental problems from the timber industry and the forest cover in Ghana need to be carefully considered in decision making processes to achieve the optimal way to address the associated problems in the environment, economy and society.

Related environmental studies about the timber sector

The environmental impact of the timber sector has received considerable attention from the research community. This section presents a broad overview of international studies on the environment impact and technologies to reduce this impact. Since this thesis focuses specifically on the environmental management of the timber sector in Ghana. It would be worth reviewing some selected environmental studies, but there apparently do not exist such studies about Ghana. The study in this section is presented as follows: identification and quantification of environmental impact, studies on environmental improvement measures.

International studies

Studies on identification and quantification of environmental impacts

Several international studies exist on the identification and quantification of the activity level and emissions of pollutants from the timber sector. The consumption of raw materials and energy (activity levels) for the forestry and forest products and associated emissions were studied notably in Norway by (Michelsen et al 2008, Solli et al. 2009), Sweden by (Lindholm and Berg 2005, González-García et al. 2009b) and Spain by (Gasol et al. 2008, González-García et al. 2009c). The results are presented in terms of consumption and pollutant loading per unit product for each major activity. To achieve a better understanding of individual environmental issues, many studies have paid attention to specific pollutants. For instance, energy use by Lindholm and Berg (2005), wood waste- related emissions by Rivela et al (2006b) and material and energy-related emissions by González-García et al. (2009c). The environmental evaluation of products, production processes and services had profound implications for the timber sector.

Studies on environmental improvement measures

Several studies on measures to improve the environmental impacts of the timber sector and other related sectors exist. Most of these studies are emission and wood waste-related. This is because emission and wood waste are considered to be the major contributors to environmental problems caused by the timber sector. Options to improve emission and wood waste impact can be categorized as reduction at the source, recycling and product modification. Most reduction at source options aims to minimize the use of wood materials and emissions. Several pollution prevention options were suggested for reduce emissions and waste for e.g. industrial waste reuse and pollution prevention by Tsai (2010), wood waste recycling by Obata et al. (2006), and wood waste management practices and strategies to increase sustainability standards in wooden furniture manufacturing sector by Daian and Ozarska (2009). From these studies it can be concluded that combinations of these reduction options could go a long way to improve the environmental impact of the timber sector.

Problem-setting

There has not been any extensive environmental system analysis of the timber sector in Ghana. Environmental problems at present are not only occurring at the regional scale, but also at the global scale, which poses potential environmental damage in the country. According to the review of international studies, some knowledge gap exists. There is, for example, no connection and understanding in addressing the numerous environmental problems in the Ghanaian timber sector. This calls for an integrated environmental assessment studies to link the sustainability and a systematic analysis of the causes of environmental problems in the timber sector. Such integrated study will be able to assess the possible options and strategies to sustain and improve its environmental performance. Analyzing the environmental performance of the sector therefore provides an effective first step to enhance the sustainability of the timber sector in Ghana. An analysis of the sustainability and the environmental impact of the timber sector are important for strategic planners and decision makers.

Study objective and research questions

Overall objective and research questions

The overall objective of the study is to assess the possible options and strategies to sustain and improve the environmental performance of the timber sector in Ghana. Analyzing the environmental performance of the sector therefore provides an effective first step to enhance the sustainability of the Ghanaian timber sector. To achieve this objective, the following research questions are addressed:

1. Is the timber sector in Ghana sustainable?
2. What is the most dominant environmental pressure for the five major production lines in the Ghanaian timber industry, and what is the influence of the choice of functional unit?
3. What does the most dominant environmental pressure contribute to the life cycle impact of the timber sector in Ghana?
4. Which potentials improvement options and strategies are available for reducing the major environmental impact in the timber sector in Ghana?

Scope of the study

In this thesis, the timber sector is divided into two subsystems: the forestry subsystem and the timber industry subsystem. The main activities of the forestry subsystem includes: harvesting of timber, skidding, processing of timber into logs, loading and transportation to company gate. The timber industry subsystem includes: energy generation, secondary production (sawmill, ply mill, veneer mill), tertiary production (furniture parts) and transportation. The five major production lines in the timber industry selected include air dried lumber, kiln dried lumber, plywood, veneer and furniture parts. This thesis considered only the tropical natural forestry but did not take forest plantation into consideration because it’s now being developed in Ghana and it’s of minor importance to this study.

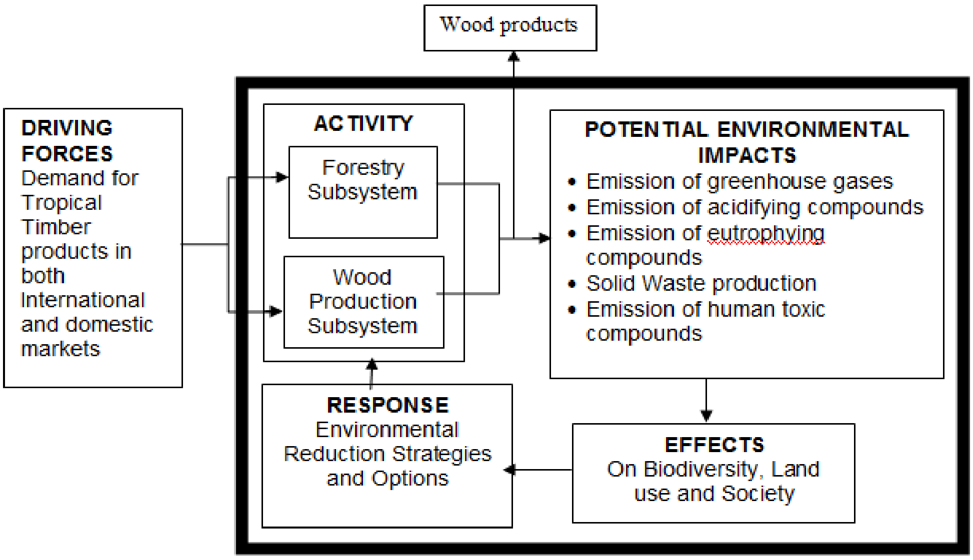

Figure 1.0: Schematic overview of the timber sector in Ghana and study guide.

Methodology

Figure 1.0 shows the schematic overview of the timber sector in Ghana and study guide. The overall objective of the study is to assess the possible options and strategies to sustain and improve the environmental performance of the timber sector in Ghana. Analyzing the environmental performance of the sector therefore provides an effective first step to enhance the sustainability of the timber sector in Ghana. This study was performed in four stages so as to take into account the research questions.

Stage 1: Is the timber sector in Ghana sustainable?

Recently, the concern about environmental impacts has gone beyond relying on existing national regulation because international markets are increasingly demanding environmentally sound products. Most international timber certification schemes allow consumers to choose timber products which has been sourced from forests deemed to be managed sustainably. Therefore, life cycle thinking has become a key focus in environmental integrated product policy and an effective integration of life cycle thinking in the timber sector is considered as a critical success factor for more sustainable industrial models (Ometto et al. 2006, Swarr 2006, Huang et al. 2007, Sundkvist and Finnveden 2007, Lilja and Liukkonen 2008, Rau and OuYang 2008).

To begin the study on assessing the possible options and strategies sustain and improve the environmental performance of the Ghanaian timber sector, it is necessary to assess whether the timber sector is sustainable as a results of its numerous environmental concerns. Analyzing the sustainability of the timber sector is complex because of a variety of economic, environmental, political, and social and culture dimensions. Such study requires a more integrated approach in identifying and bridging sustainability gap in order to reduce the total environmental burden of the timber sector. This section takes care of research question (1): Is the timber sector of Ghana sustainable?

Assessing sustainability issues in timber sector require a well-established methodology. This methodology must be based on long-term, repeated measurements to ensure accurate assessment of trends and its statistical significant relationships between causes and effects. There are number of frameworks of sustainability assessment methods that evaluate the performance of companies. Some of these sustainability frameworks include, the World Business Council for Sustainable Development (WBCSD 1997), the Global

Reporting Initiative (GRI 2002) and development of standards (OECD 2002). Azapagic (2004) for the mining and minerals industry, and Krajnc and Glavic (2005) for other companies. These sustainability frameworks are increasingly recognized as a useful tool for policy making in fields of environment, economy, society, or technological development. It is interesting to note that companies have been struggling to come into consensus key performance indicators that describe causal linkages that can be leveraged to drive sustainability initiatives (Epstein and Roy 2001).

To help decision makers in this study, it was useful to use a composite sustainable approach, linking many sustainability issues and so reducing the number of decision-making criteria. This study therefore adapted the method used by Sulser et al (2001) in assessing biophysical sustainability in agriculture systems in Northern Ecuador and recommended it as quick, easily applied and facilitate effective assessment process. This method uses a structured closed-ended questionnaire, followed by in-depth personal interviews with selected stakeholders. Responses on economic, social and environmental consequences are then measured by sustainability indicators on a three point Likert scale (good, moderate and bad). The Likert scale measures responses to a statement and is most widely used in survey research (Likert 1932, Sulser et al. 2001, Skevington et al. 2004). This scale has gained popularity in recent research mainly due to its simplicity and reliability. This makes the Likert scale a more appropriate tool for this stage of this thesis. The results of this study are then used as basis for identifying and bridging sustainability gap in order to reduce the total environmental burden.

Stage 2: What is the most dominant environmental pressure for the five major production lines in the Ghanaian timber industry, and what is the influence of the choice of functional unit?

Life Cycle Assessment (LCA) is a tool to assess the environmental performance of, and to identify the environmental hotspots in a product chain. A product life cycle approach provides a useful framework for studying the link between societal needs, the nature and economic processes involved in addressing the needs, and associated environmental consequences. A LCA assessment according to definition of the International Standard Organisation (ISO) is a compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle (ISO - 14044 2006). The ISO standard provides international reference with respect to principles, framework and terminology for conducting and reporting life cycle assessment studies. LCA methodology has been used for assessing the environmental impact of industrial products for decades (González-García et al. 2009c). LCA conducted by González-García et al (2009c) focus on material and energy-related emissions. Other Life-cycle assessment studies includes; (Lippke et al 2004); (Perez-Garcia et al. 2005). In accordance with the ISO standard, an LCA consists of four interrelated phases (Figure 1.1), as presented as follows:

The first phase is 'Goal and scope definition'. This is the planning phase of the study where all the specifications of the study are defined including the goal of the study; the scope definition; the functional unit; system boundaries; the quality of data; the critical review process. The functional unit provides the reference to which the environmental inputs and outputs of a product system are related (ISO - 14044 2006). It defines the service of the studied products in relation to user requirements and is typically expressed as the unit service for a specified period of time. The functional unit must include both a qualitative and quantitative description of the products service provided to the user so that the product can be compared on a fair basis. Defining the system boundaries enable the distinction between the product system and the environmental. Furthermore, it divides the relevant from the irrelevant processes and process flows (Guinée et al 2001). The system boundaries have a significant influence on the outcome and the informative value of the studies (Nerquaye-Tetteh 2001). This is where the system inputs; outputs and their relationship are identified and described. Appropriate system definition is essential for the identification of relevant reduction options to the problem studied (Findeisen and Quade 1997). Here an appreciation of this problem is important in order to make appropriate decisions to reduce environmental impact (Jensen et al 1997).

The second phase is the 'Life cycle inventory' which involves the compilation and quantification of inputs and outputs in all the involved processes. Outputs include both material outputs (e.g., one cubic meter of Furniture part), emissions (e.g., Carbon dioxide) waste (e.g., Wood waste). In this phase it should also be decided how to handle processes producing more than one product. Inventory analysis identifies and quantifies the resources extracted and consumptions, and the environmental releases relating to the processes that make up the life cycle of the examined product(s). These extractions, consumptions and environmental releases are also referred to as environmental interventions. The interventions are expressed as quantities per functional units. The result of this study only quantifies interactions between economic and environmental processes.

The third phase is the 'Life cycle impact assessment', which is carried out on the basis of the life cycle inventory data. First, the emissions in the life cycle inventory data are classified, which means they are assigned to categories according to their impact. For example, methane is a greenhouse gas and is hence assigned to the impact category 'Global warming'. If a substance contributes to more than one impact category, it is assigned to all of them. Classification is followed by characterization. Every substance is assigned a potential impact in the impact category under study. The potential impact of a substance is given relative to a dominant factor in the category, for example, for the global warming potential this is typically 1 kg of CO_2 emissions. These relative impacts (the characterization factors of a substance) are then multiplied with the amount of each emission and the resulting impact values are summed for the respective impact category (ISO - 14044 2006). The purpose of impact assessment is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance for making informed decisions.

The fourth phase is interpretation. In this phase the data from the inventory phase and the impact assessment phase are combined in line with the defined goal and scope of the study. Here, conclusions and recommendations to the decision makers may be drawn, unless reviewing and revising of previous phases is needed. For further description on the LCA methodology, see e.g., ISO standard (ISO - 14044 2006).

This second stage in this thesis takes care of research question (2): What is the most dominant environmental pressure for the five major production lines in the Ghanaian timber industry, and what is the influence of the choice of functional unit? In this stage, the first and second phases of LCA are applied (Figure 1.1). To accomplish the above research questions, questionnaires are administered to selection timber companies in Ghana. Information data base are obtained from both primary and secondary sources from the forestry and timber industry subsystems in Ghana and other scientific literatures. Life cycle inventory (LCI) is compiled within the process boundaries. The results of this stage are used as a basis for the analysis in subsequent phases.

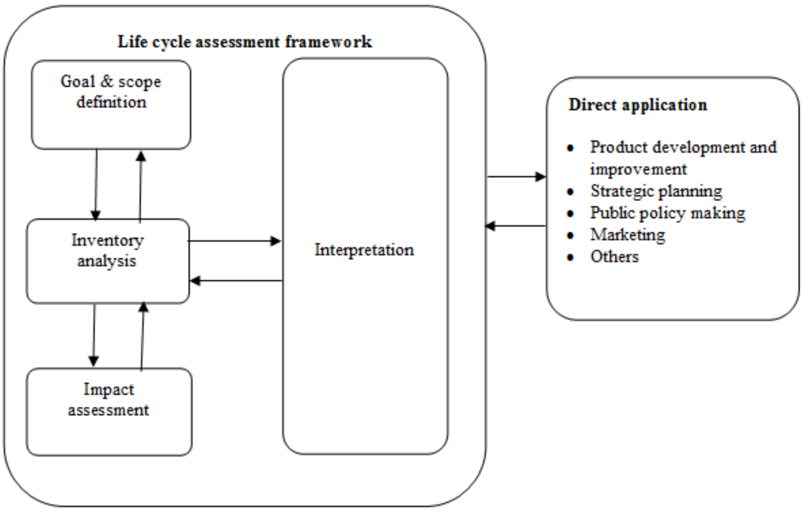

Figure 1.1: The phases of an LCA according to ISO 14044 (2006)

Stage 3: What does the most dominant environmental pressure contribute to the life cycle impact of the timber sector in Ghana

This stage takes care of the research question (3): What does the most dominant environmental pressure contribute to the life cycle impact of the timber sector in Ghana? In this stage, the third phase of LCA is applied (Figure 1.1). This study uses the previous LCI study (Stage 2) as a starting point for an additional LCIA. The LCIA aims at evaluating the significance of potential environmental impact of the results of inventory analysis (the second phase of an LCA), within the framework of the defined goal and scope of the study (first phase on an LCA) (ISO - 14044 2006).

Stage 4: Which potentials improvement options and strategies are available for reducing the major environmental impact in the timber sector in Ghana?

This stage addresses research question (4): Which potentials improvement options and strategies are available for reducing the major environmental impact in the timber sector in Ghana?

This study explores the possibility of minimizing major environmental impact in the sector. Additional information from forestry, and about the state of equipment/machinery and potential for improvement in the whole timber sector are established through interviews with experts, actual plant observations and reviewing of literature (Cohen and Allen 1992, Mulholland and Dyer 2001, Musee et al. 2007).

This information is used for the identification of the sources and types of potential impact, the causative analysis of the potential impact and feasible potential impact minimization measures. Scenarios analysis is then used for making a strategic planning for the future in minimizing other environmental potential impacts in the timber sector of Ghana. The results of this study will provide an insight of the different strategies and options to enhance sustainability of the timber sector in Ghana.

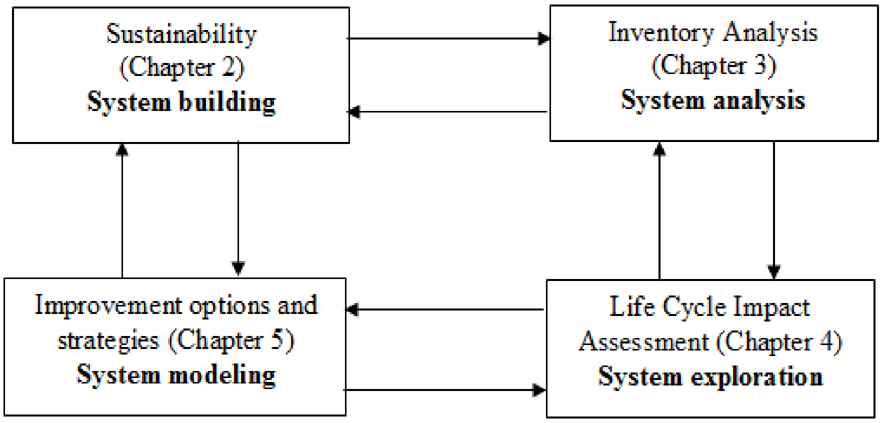

Figure 1.2: Summary overview of the investigated relationships diagram for the study (according to chapters) of environmental life cycle assessments to enhance the sustainability of the timber sector in Ghana.

Outline of the Thesis[1]

The outline of this thesis follows the objectives and methodologies described above. This thesis contains six chapters presenting the results of the four stages of the environmental assessment of the timber sector in Ghana. Figure 1.2 summaries the overview of the investigated relationships diagram for the study (according to chapters) of environmental assessments of the timber sector in Ghana.

Chapter 1 provides a general introduction which describes the background of the study of the environmental assessment of the Ghanaian timber sector. This section is where the problem of the timber sector is formulated and the research questions of this thesis are introduced and the goal and scope definition of the thesis are clarified. The last section provides the outline of the study to facilitate the reading of this thesis.

Chapter 2 presents an overview and a thorough understanding of the sustainability issues in the timber sector of Ghana. This understanding helps to identify and bridged the sustainability gap to avoid the immanent depletion of the natural forest resources to sustain the timber sector.

Chapter 3 provides an inventory analysis of the timber industry. The purpose of this study is to compile a comprehensive Life Cycle Inventory (LCI) to identify the most dominant environmental pressures for the five major production lines in the Ghanaian timber industry, and to evaluate the influence of the choice of the functional unit on the results. The results of this study are very useful in revealing the current, material, waste, and greenhouse emissions inventories for the timber industry.

Chapter 4 provides the contribution of the most dominant environmental pressure to the life cycle impact assessment for the timber sector in Ghana. LCIA provides additional information to help assess a product system's LCI results so as to better understand their environmental significance. Such LCIA study also helps the sector to prioritize areas for environmental action and, at the same time, get the best return on their investments by reducing their operational environmental impact.

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[1] Chapters 2 to 5 are published as articles in peer-reviewed international scientific journals in the field of forestry, LCA and cleaner production and can therefore also be read separately.

Chapter 5 explores the possibility of minimizing potential environmental impact in the timber sector. This study ensures that the best potential impact minimization options and strategies are selected and implemented to improve the environmental performance and enhance sustainability of the timber sector in Ghana.

Chapter 6 discusses all the previous chapters and draw conclusion and recommendations for future research.

Chapter 2: Sustainability of the timber sector in Ghana

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Chapter 2: Sustainability of the timber sector in Ghana

Abstract

This paper provides an overview and a thorough understanding of the sustainability issues in the timber sector of Ghana. This understanding will help to identify and bridge the sustainability gap to avoid the immanent depletion of the natural forest resources. The sector was assessed by means of a structured closed-ended questionnaire, followed by in-depth personal interviews with selected stakeholders. Responses on economic, social and environmental consequences of the timber sector were measured by sustainability indicators on a three point Likert scale. The sustainability gap has been identified and it is expected to widened, if major policy interventions are not implemented and respected. To achieve sustainability the study concludes by suggesting a number of approaches to bridge this sustainability gap in order to make the timber sector sustainable.

Keywords: Sustainability, Ghanaian timber sector, economic, social, environment

Introduction

The state of tropical rain forest and its rate of destruction have raised international concerns. These concerns have led to an increased interest in the role of tropical timber production and international timber trade in sustainable development in the tropics (ITTO 2005, Adams 2006, IISD 2009). Achieving sustainability requires balancing the complex relationships between current environmental, economic and social needs in a manner that does not compromise future needs (Brundtland 1987). A sustainable industrial development of wood extraction and processing in the tropics involves protecting and improving the natural environment of the local communities, while at the same time being productive and efficient (Kowero et al. 2001).

Ghana is endowed with a rich natural tropical forest base. In 2006, this forest base has contributed significantly to economic growth through timber product export (Ghana Gazette 2005). The timber sector achieved a growth rate of 5.6%, and its total production contributed 3.5% to total gross domestic production (GDP) in Ghana (TIDD 2007). Despite this economic growth, the current environmental and social situation in the timber sector continues to deteriorate. This can be seen from the ongoing dwindling natural tropical forest base, low production recovery rates, wood wastes, illegal chainsaw activities, biodiversity loss and a multitude of other direct and indirect problems (FOSA 2001, FAO 2005c).

The concept of sustainable development has been incorporated in the past decade in several policy documents in the Ghanaian timber sector (Coleman 1991, Driver 1995 , EPA 1999, FOSA 2001). It is questionable, however, whether these policies and agreements led to significant positive environmental and social changes. There appears to be a gap between sustainability policies and their implementations in the Ghanaian timber sector. This gap is rooted in a competition between the formal and informal sector for the same resource base, i.e. wood or forest reserve, which unfortunately represents an example of the so-called “tragedy of the commons”. Such tragedy is a dilemma arising from the situation in which multiple stakeholders, each driven by their short-term self-interest, will ultimately deplete a collective but limited resource. This is obviously not in anybodies’ long-term interest (Hardin 1968).

The case of the timber sector is analogously exemplified here as a tragedy of the commons. This tragedy may arise as a result of the competition between the informal and formal timber sectors to supply wood. This competition is rooted in the exploitation of the common forest resource to maximize individual benefits, even if the annual allowable cut for the forest is exceeded, or the forest is completely destroyed, while the actual damage to the forest resource is shared by society.

The clash of the formal and informal sector goes to the heart of sustainability. Figure 2.0 shows economic activity in the formal timber sector in Ghana. The existence of an informal timber sector next to the formal timber sector is an important factor hampering the implementation of sustainability policies in Ghana. The existence and activities of the informal timber sector results from social neglect, low incomes and widespread poverty. Considering the slow increase in opportunities for formal sector employment, the informal sector employment is expected to grow. Some of the consequences of the formal and informal complexities on the forest could undermine the capacity to sustain the timber industry and therefore widen the sustainability gap (Kowero et al. 2001).

It is important to help policy makers and other stakeholders in the Ghanaian timber sector to identify and bridge the sustainability gap. There is therefore an urgent need to study and understand the formal and informal complexities in the quest to achieve sustainable development goals so as to avoid the tragedy of the 'commons'.

This study aims to provide an overview and a thorough understanding of the sustainability issues in the timber sector of Ghana by determining the differences in the performance of the formal and informal forest sectors. Understanding of this sustainability gap will help to meet the future challenges of maximizing the role of the timber sector in economic, social and environmental development. It is therewith relevant for policy makers and other stakeholders in the timber sector.

The methodology will be presented in the next section. The subsequent sections will present and discuss the economic, social and environmental consequences. We will show the importance for collecting more relevant information from local and national stakeholders. Such information and the subsequent understanding are urgently needed to sustain the timber sector in Ghana.

Materials and methods

The natural tropical forest of Ghana is located in the South and South Western parts of the country. The major natural tropical forest regions are the Central, Ashanti, Western, Brong Ahafo and Eastern regions of Ghana. Natural tropical forest is the main source of raw material supply to the timber industry and also provides livelihood for numerous local communities within these areas. This study was carried out in these selected five regions because of their significant contributions to timber product export.

Most of the existing literature and data relates to the formal timber sector and contains little information about the informal timber sector in Ghana. To fully understand the relation between the formal and informal timber sector, we needed to supplement the existing data with information from a structured closed-ended questionnaire and personal interviews.

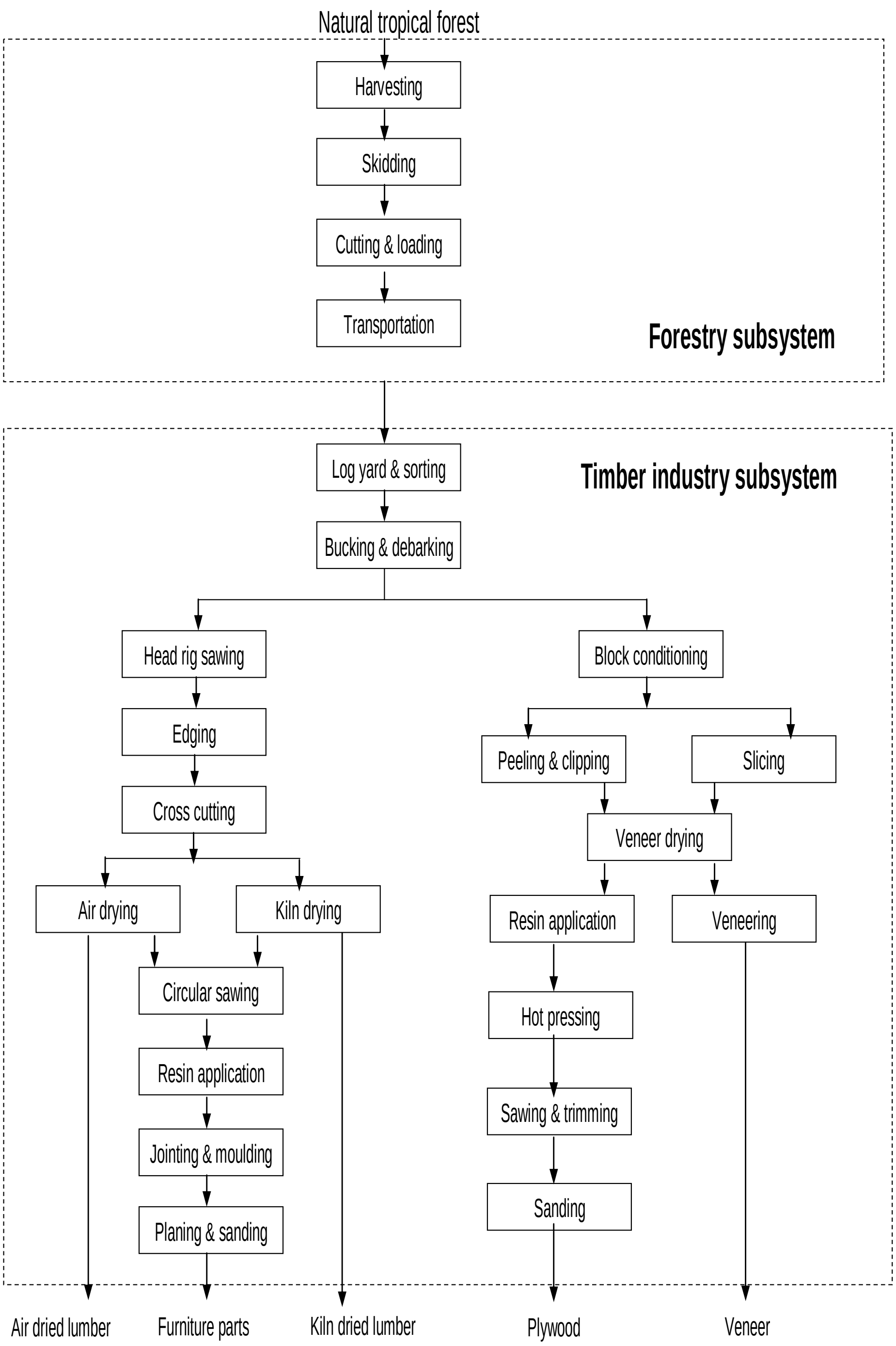

Figure 2.0: Flow chart of the activities in the formal timber sector in Ghana. Competition between the formal and informal sector mainly takes place on the activities in the forestry subsystem.

Survey questions

Respondents to the questionnaire were asked to assess the sustainability of the timber sector based on its economic, social and environmental impacts. Table 2.0 and Table 2.1 give an overview of the sustainability indicators included in our survey. The selection of sustainability indicators was based on experts and stakeholders experience and the practical sustainability issues put forward during a stakeholders meeting of the timber sector in Ghana as part of this research project. The questionnaires were tested for clarity and the relevance of the feedback on its design and content by a few experts from the Ghana Timber Industry Development Division.

Response levels of respondents were measured on a three point Likert scale (good, moderate and bad). The Likert scale measures responses to a statement and is most widely used in survey research (Likert 1932, Sulser et al. 2001, Skevington et al. 2004). This scale has gained popularity in recent research mainly due to its simplicity and reliability. Sulser et al (2001), for example, used this method in assessing biophysical sustainability in agriculture systems in Northern Ecuador and recommended it as quick, easily applied and facilitate effective assessment process. The approach was therefore adopted in this study.

Survey sample and procedure

The selection of the respondents was based on consultation with experts from the Timber Industry Developments Division and Resource Management Support Centre (RMSC) of the forestry commission in Ghana. The structured closed-ended questionnaires were administered among a carefully selected sample of fifty stakeholders, ten from each selected forest region. The ten respondents for each region consisted of assembly members (community leaders) in two timber forest fringe communities and of workers, managers of industrial operations, and managers of forestry operations from two timber companies and officials from the two government agencies in the timber sector.

A total of ten forest fringe communities, two in each region, were thus selected. The selection of the forest fringe communities were based on the uniqueness of forest degradation in that area, and its rich contributions to that problem. The total of ten timber companies was also selected based on their forest utilization contract rights in that selected area. The selections of the sample were considered to be representative as far as the practical sustainability issues of the timber sector in Ghana are concerned.

The questionnaires were completed in the presence of the first author and afterward supported with personal interviews.

Survey analysis

All fifty questionnaires were administered in the five selected forest regions of Ghana and returned (i.e. a response rate of 100%). This high percentage questionnaire output was as a result of the researcher’s personal involvement in their distribution and administration. The questionnaires were first sorted out into the five forest regions of Ghana. The responses for each indicator and each region were counted according to the three point Likert scale rating. The total indicator ratings for all the five regions were averaged to give a percentage overview of sustainability indicators for the timber sector in Ghana. Next, results were similarly sorted, counted and averaged into the five stakeholder groups.

Survey results and interpretation

Table 2.0 and Table 2.1 quantitatively summarize the response on the questionnaire from the five stakeholder groups and in the five forest regions of Ghana. The following chapters will present the results of the survey and personal interviews on sustainability in the timber sector in Ghana. Next these results are discussed in relation to information about the Ghanaian timber sector from literature, statistical data and satellite imagery. Land satellite imagery of selected forest reserves was collected from the Resource Management Support Centre (RMSC) of the forestry commission in Ghana. Additionally, statistical data on wood products exports from 2000 to 2007 were collected from the Ghana Timber Industrial Development Division (TIDD) to complement the study. Literature and research reports on sustainability were also reviewed as part of the study.

Table 2.0: Survey responses for the sustainability indicators of the timber sector from the five regions of Ghana (A = Good B = Moderate C = Bad)

	Ashanti			Brong Ahafo			Central			Western			Eastern			Share in total %		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Economic impacts																		
Products market	10	0	0	8	2	0	6	4	0	10	0	0	7	3	0	**82**	**18**	**0**
Technology & investment	3	5	2	2	6	2	2	3	5	2	6	2	1	3	6	**20**	**46**	**34**
Production management	2	6	2	3	5	2	3	2	5	3	5	2	2	3	5	**26**	**42**	**32**
Scale effect	3	5	2	2	6	2	3	7	0	2	5	3	3	6	1	**26**	**58**	**16**
Social impacts																		
Corporate social responsibility	2	3	5	0	3	7	1	4	5	1	0	9	1	2	7	**10**	**24**	**66**
Employment rate	1	3	6	0	2	8	0	1	9	0	3	7	1	4	5	**4**	**26**	**70**
Poverty alleviation and eradication	3	4	3	1	5	4	0	2	8	1	6	3	1	3	6	**12**	**40**	**48**
Access to social security	2	3	5	1	4	5	3	3	4	1	3	6	2	3	5	**18**	**32**	**50**
Labour rights violations	0	3	7	1	4	5	0	4	6	0	2	8	1	3	6	**4**	**32**	**64**
Occupational health and safety	1	5	4	3	4	3	2	3	5	3	4	3	2	5	3	**22**	**42**	**36**
Training and educational	1	5	4	3	5	2	2	2	6	1	4	5	2	6	2	**18**	**44**	**38**
Productivity loss from corruption	1	2	7	0	2	8	0	0	10	0	2	8	1	2	7	**4**	**16**	**80**
Stakeholders involvement	2	5	3	1	6	3	2	5	3	1	5	4	1	7	2	**14**	**56**	**30**
Environmental impacts																		
Pollution	2	5	3	1	3	6	0	4	6	3	3	4	3	1	6	**18**	**32**	**50**
Wood waste	0	2	8	0	4	6	0	0	10	1	3	6	2	3	5	**6**	**24**	**70**
Deforestation rate	1	3	6	1	3	6	1	2	7	2	3	5	1	3	6	**12**	**28**	**60**
Land use change	0	4	6	1	3	6	0	4	6	0	3	7	1	4	5	**4**	**36**	**60**
Biodiversity loss	1	2	7	0	4	6	2	3	5	2	3	5	1	3	6	**12**	**30**	**58**

Table 2.1: Survey responses for the sustainability indicators of the timber sector from the five selected stakeholders in Ghana (A= Good B= Moderation C= Bad)

	Government agencies			Community leaders			Forestry managers			Industry managers			Timber workers			Share in total %		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Economic impacts																		
Products market	4	6	0	10	0	0	8	2	0	9	1	0	10	0	0	**82**	**18**	**0**
Technology & investment	2	6	2	2	2	6	2	6	2	2	6	2	2	3	5	**20**	**46**	**34**
Production management	2	5	3	3	2	5	3	4	3	3	5	2	2	5	3	**26**	**42**	**32**
Scale effect	3	7	0	2	5	3	3	5	2	2	6	2	3	6	1	**26**	**58**	**16**
Social impacts																		
Corporate social responsibility	2	3	5	1	0	9	1	2	7	1	4	5	0	3	7	**10**	**24**	**66**
Employment rate	1	4	5	0	4	6	1	0	9	0	3	7	0	2	8	**4**	**26**	**70**
Poverty alleviation and eradication	2	5	4	0	2	8	1	5	4	2	5	3	1	3	6	**12**	**40**	**48**
Access to social security	3	3	4	1	3	6	2	3	5	2	3	5	1	4	5	**18**	**32**	**50**
Labour rights violations	1	4	5	0	3	7	0	4	6	1	3	6	0	2	8	**4**	**32**	**64**
Occupational health and safety	3	4	3	2	3	5	1	5	4	3	4	3	2	3	5	**22**	**42**	**36**
Training and educational	3	5	2	2	2	6	1	5	4	2	6	2	1	4	5	**18**	**44**	**38**
Productivity loss from corruption	1	4	5	0	0	10	1	2	7	0	1	9	0	1	9	**4**	**16**	**80**
Stakeholders involvement	2	5	2	1	7	2	2	5	3	1	5	4	1	6	3	**14**	**56**	**30**
Environmental impacts																		
Pollution	3	3	4	0	4	6	3	2	5	2	5	3	1	4	5	**18**	**32**	**50**
Wood waste	1	3	6	0	0	10	0	0	10	2	3	5	0	4	6	**6**	**24**	**70**
Deforestation rate	2	2	6	0	3	7	1	3	6	2	3	5	1	3	6	**12**	**28**	**60**
Land use change	1	3	6	0	4	6	1	4	5	0	3	7	0	4	6	**4**	**36**	**60**
Biodiversity loss	2	3	5	0	4	6	1	2	7	2	3	5	1	3	6	**12**	**30**	**58**

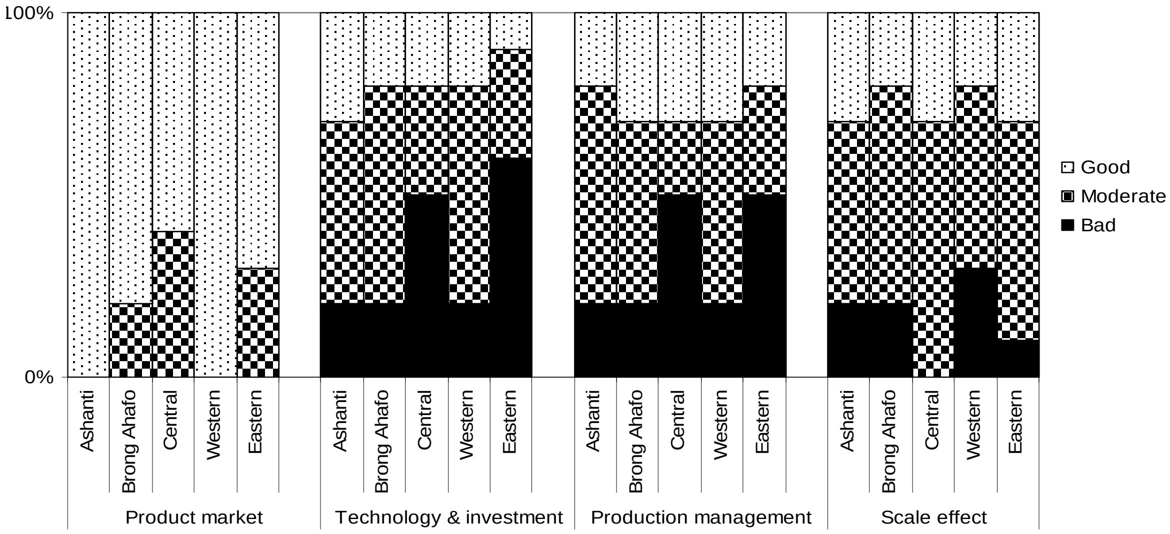

Figure 2.1: Summary of average response on the economic impact of the sustainability of the timber sector in selected forest regions of Ghana

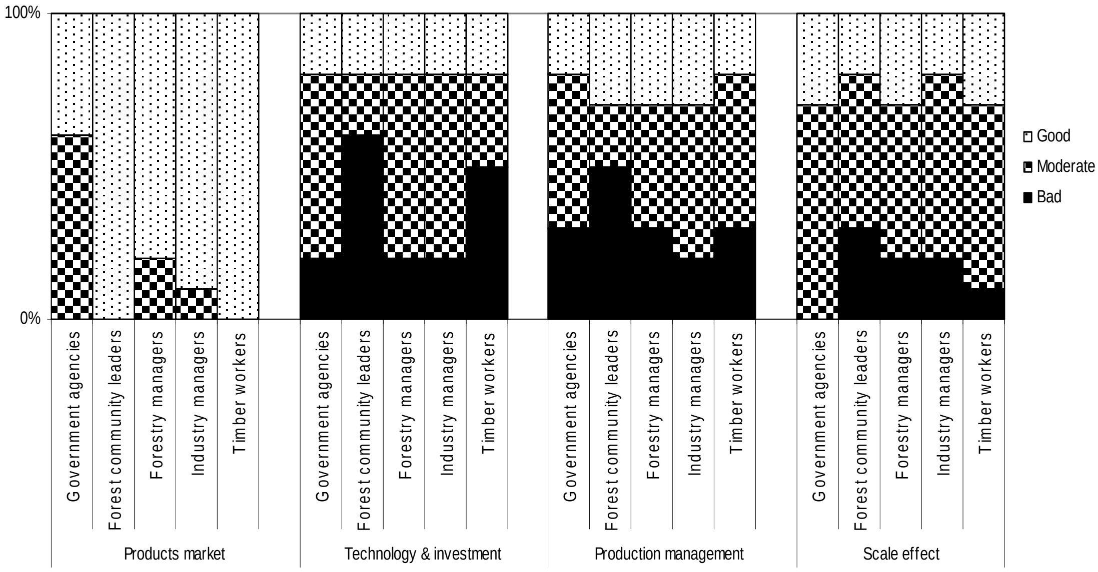

Figure 2.2: Summary of average response of selected stakeholders on the economic impact of the sustainability of the timber sector in Ghana.

Results – Economic impact

The economic assessment of the timber sector includes its product market impact, technology and investments impact, production management and scale impact. Figure 2.1 and 2.2 graphically illustrate the summary of the results.

Product market impact in the survey measures the difference in market prices of wood products between the various communities and regions. The survey results for all the selected stakeholders, except the government, gave a positive product market impact (Table 2.1). The majority of respondents, i.e. 82%, considered the product market impact as good (Table 2.0). This means that wood products, specifically lumber, are available against a fair price. However, the additional interviews revealed that the formal wood supply does not meet the local market demand. The local market demand for wood, particularly lumber, was identified as a major driver for informal timber sector activities as illegal chainsaw operations in the timber sector of Ghana. According to Table 2.0, Ashanti and Western regions recorded the highest positive product market impact values. These two regions constitute the largest forest reserves compared to the other regions and have the greatest regional influence in timber production in Ghana. Secondary data from the TIDD (2007) shows a slight decrease in trade volumes and values of wood products export as illustrated in Figure 2.3 and Figure 2.4. This decrease was cited in the interview to be due to the competition for raw materials with the illegal chainsaw activities for the local market that produces for local consumption.

The technology and investment impact in the survey measures the change in the type of technology and investment induced by the sustainability timber trade policies in Ghana. The survey results indicated that 46% of the respondent considered technology and investment as moderate and 34% responded as bad (Table 2.0). Especially the central and eastern regions of Ghana indicated the technology and investment impact to be bad as a

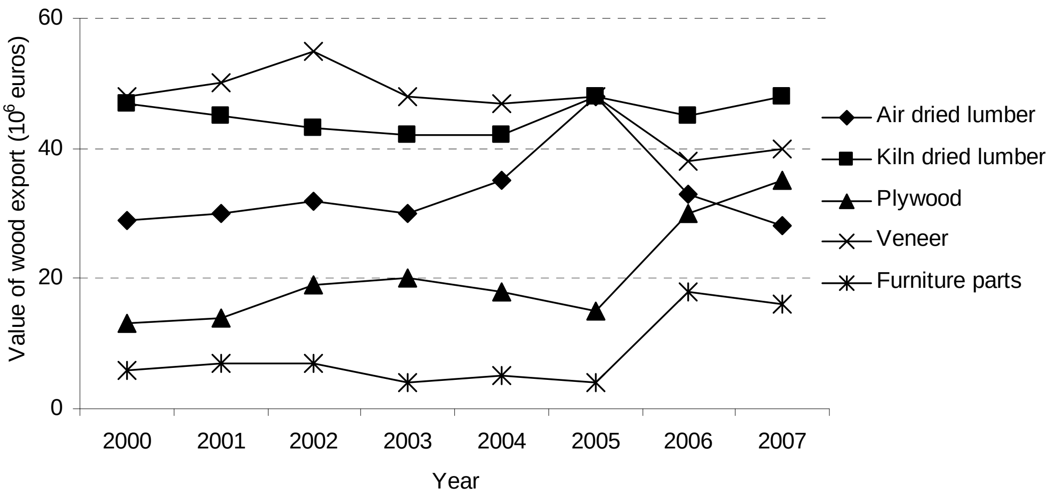

Figure 2.3: Major wood products export value from 2000 to 2007 of the Ghana timber sector

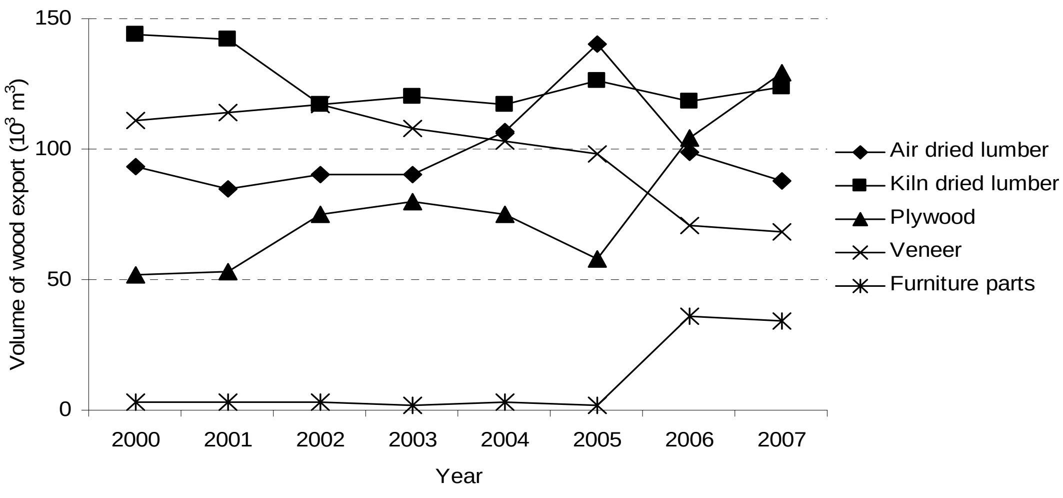

Figure 2.4: Major wood products export volumes from 2000 to 2007 of the Ghana timber sector

result of their low timber resources potential. Forest fringe community leaders and timber workers considered technology and investment opportunity in the timber sector more often as bad, as a result of the unutilized amount of wood waste generated during timber production (Table 2.1).

The production management impact of the survey measures the management quality and manpower capacity dealing with trade, production and investment policies in the timber sector of Ghana. According to the survey, 42% of the respondents considered production management impact as moderate and 32% considered it as bad (Table 2.0). All stakeholders considered production management's impact as roughly evenly moderate to bad, though forest fringe community leaders considered it more often as bad (Table 2.1). The forest fringe community leaders were of the opinion that, if the production management would have had expert knowledge in particle board, the large amount of waste could have generated additional employment. All respondents were of the view that production management competence in the timber sector in Ghana has not been impressive.

The scale effect impact measures the influence of the timber sector on the economic growth, financial gain and employments in other related sectors. The survey results show that 56% of the respondents considered the scale effect impact of the timber sector as moderate (Table 2.0). This indicates that the growth in timber sector investment has not been impressive and therefore only made a low contribution to national employment rates and financial gains in related sectors. Respondents were of the view that the deterioration of the roads network are caused mainly by timber haulage activities.

Results – Social impact

The social impact indicators considered in the study were corporate social responsibility, employments rate, poverty alleviation and eradication, access to social security, labour rights violations, occupational health and safety, training and education, productivity loss from corruption, and stakeholders' involvement. The summary of the results is illustrated in Figures 2.5 and 2.6.

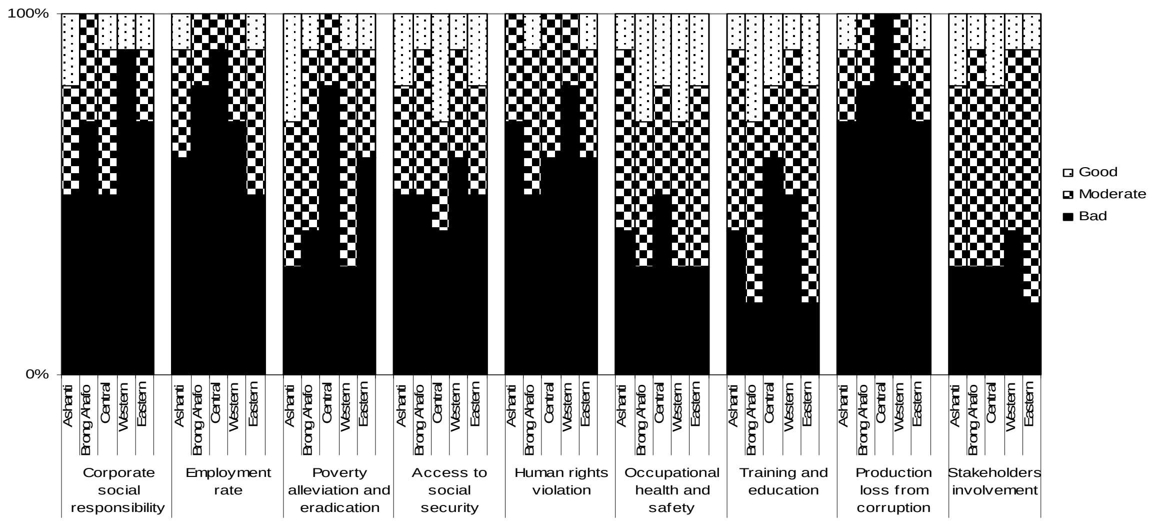

Figure 2.5: Summary of average response on the social impact of the sustainability of the timber sector in selected forest regions of Ghana

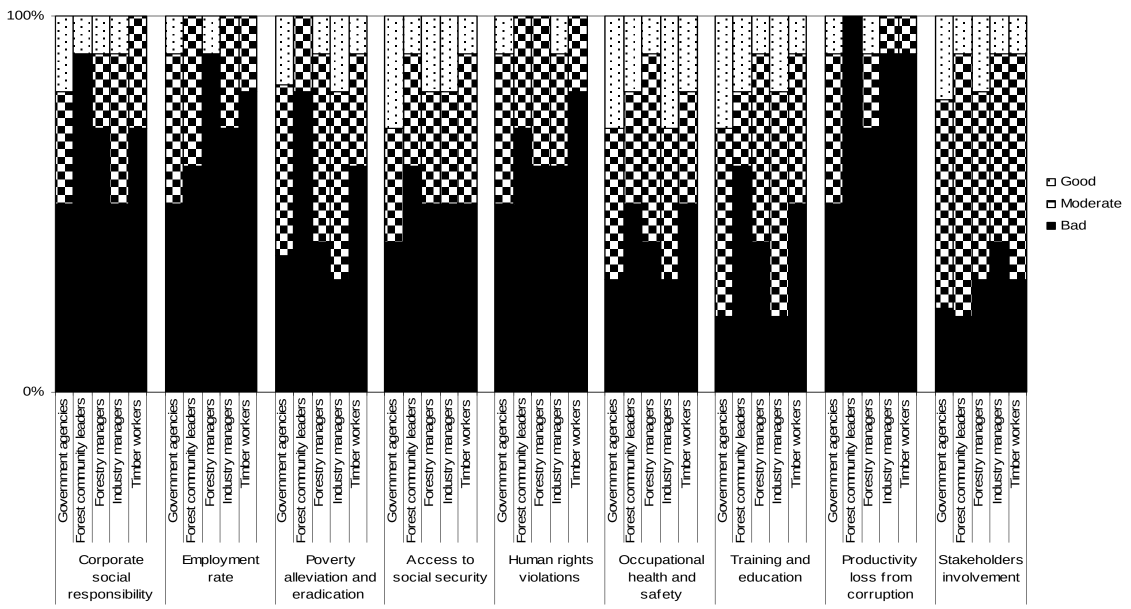

Figure 2.6: Summary of average response of selected stakeholders on the social impact of the sustainability of the timber sector in Ghana

Corporate social responsibility impact in the survey measures the general commitment of the timber companies to the social responsibility agreements about all other social issues in this section. The survey results show that 66% of the respondents consider the corporate social responsibility of the timber companies as bad (Table 2.0). Another 24% value it as moderate. The timber companies are considered to be not faithful to their commitments and this were evident in all forest regions and selected stakeholders' respondent in Ghana as shown in Tables 2.0 and 2.1.

The 90% bad to moderate performance of the timber companies on corporate social responsibility is reflected in the responses of all stakeholders in all regions to the other social impact indicators. Government agencies and industry managers also predominantly respond moderate to bad, but show structurally more positive responses then other stakeholders. This is because the timber rights fees are paid to the government agencies when timber companies are awarded Timber Utilization Contract (TUC) of which social responsibility agreement forms part. However, these economic benefits are not realized by the other stakeholders.

The employment rate impact in the survey measures whether the formal timber sector provides sufficient jobs to the working age population (ages 18 to 60). This impact was rated as bad by 70% of the respondents (Table 2.0). They attributed the insufficient job provision to the slow growth in investments. The bad employment situations were cited across all selected forest regions and stakeholders in the timber sector. Respondents were of the view that the high rate of poverty across the communities and regions are as a result of the absence of formal employments.

The poverty alleviation and eradication impact measure the programmes carried out by the timber companies to reduce cost of living in a particular community in which they operate. The results indicate that 48% of the respondents are negative about the poverty alleviation and eradication programmes. They think that the programmes are shrouded in secrecy and not transparent. Another 40% of the respondent evaluated the poverty alleviation and eradication programmes as moderate, meaning some companies provide flexible jobs with low demands on skills as a means to improve access to income and lower poverty rates in local communities.

The social security impact measures the access to social security benefits for workers of the timber sector in Ghana. According to the survey conducted, 50% of the respondents considered access to social security benefits as bad, and another 32% as moderate. This means that most workers have no benefit to depend on after spending greater part of their life with the company. This situation makes them unable to cope with their retirement welfare and therefore force them into illegal forest activities.

Human rights violation impact in the survey measures the violation of basic rights and freedom of workers and communities in the timber sector in Ghana. The survey result shows that 64% of the respondents consider human right violation as bad. They are of the opinion that human rights of workers and communities are not respected by the timber companies. Communities also reported to experience significant human right abuses at the hands of timber companies and state officials. This includes destruction of community infrastructure and farms during timber haulage operations. Communities that have tried to resist these abuses or demanded compensation are largely ignored. In some cases farmers report threats of reprisals by timber company officials.

The occupational health and safety impact measures the performance of the timber sector on these issues. According to the survey results 42% of the respondent considered occupational health and safety impact as moderate. They indicated that occupational health issues are often given less attention than occupational safety issues in the timber sector in Ghana. A total of 36% responded as bad, because occupational health and safety management systems are not properly enforced and respected in the timber sector.

The training and education impact measures the timber sector contributions towards training and education in the various forest communities and regions they operate. Training and education in the timber sector was considered by 44% respondents as moderate. Another 38% of responded with bad, mainly because the existing training is inadequate to address the timber sector problems. Some timber companies were reported to support training and other educational programmes in their local communities in different capacities. Their support systems is in the form of provision of scholarships, sponsoring local school programmes and construction of school building as well as other community social services such as support for literacy programmes.

Productivity loss from corruption measures the abuse of power or position by official leading to productivity losses in the timber sector. According to the survey, 80% of the respondents considered corruption as bad, meaning the benefits that are supposed to come to the communities and the regions go to individuals' pocket. Corruption in the timber sector happens across all selected regions. The forest fringe communities are the most affected, and they therefore obviously respond the most negative on this impact. According to the interview conducted, government officials were cited as the most corrupt and they therefore respond the most positive on this impact.

The stakeholders' involvement impact measures the level of involvement of all those whose participation and support are crucial to the success of sustainability policy in the timber sector. The personal interviews addressed in more detail who are involved in defining timber sector and conservation objectives, determining beneficiaries, managing forest resources, resolving conflicts over forest uses, and monitoring and evaluating the performance of forestry and biodiversity conservation projects. According to the survey conducted, 56% of the respondents considered the involvement of stakeholders in decision-making in the timber sector as moderate. These respondents consider the involvement of stakeholders in decision-making processes at all levels in almost all the regions as not effective. The level of capacity of the local people is often underrated and they are sometimes involved at the last stages of decision-making.

Results – Environmental impact

The environmental sustainability of the timber sector was assessed based on the impact indicators such as: pollution, wood waste deforestation, land use change, and biodiversity loss. The summary of the results is illustrated in Figures 2.7 and 2.8.

The pollution impact measures the respondents' opinion about the presence of undesirable substance and other health effect associated with the activities of the timber sector in Ghana. Pollution in the timber sector was considered by 50% respondents as bad, meaning that pollution and its adverse effects on their health was a problem (especially dust and noise). The central region was considered as the most polluting region according to the survey in Table 2.0, and this was cited as a result of its low technology and investment impacts.

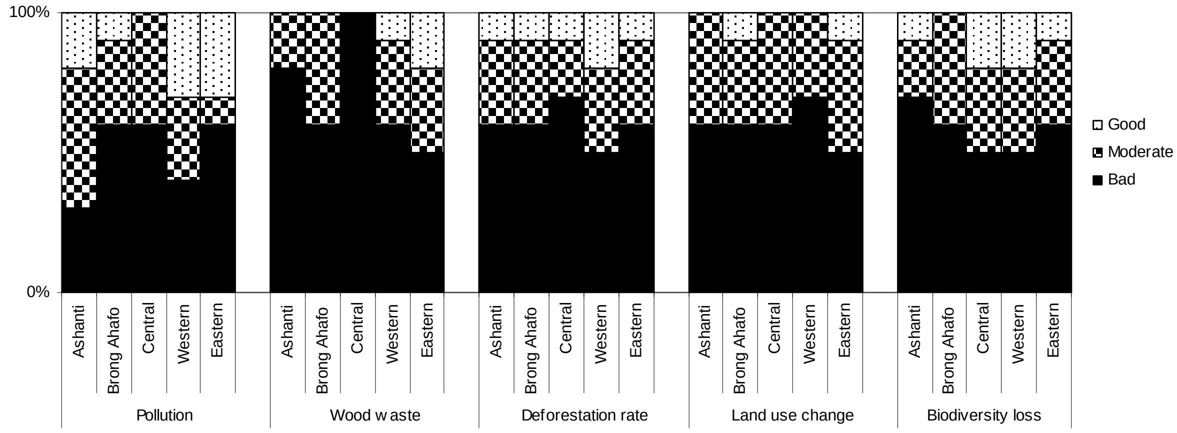

Figure 2.7: Summary of average response on the environmental impact of the sustainability of the timber sector in selected forest regions of Ghana

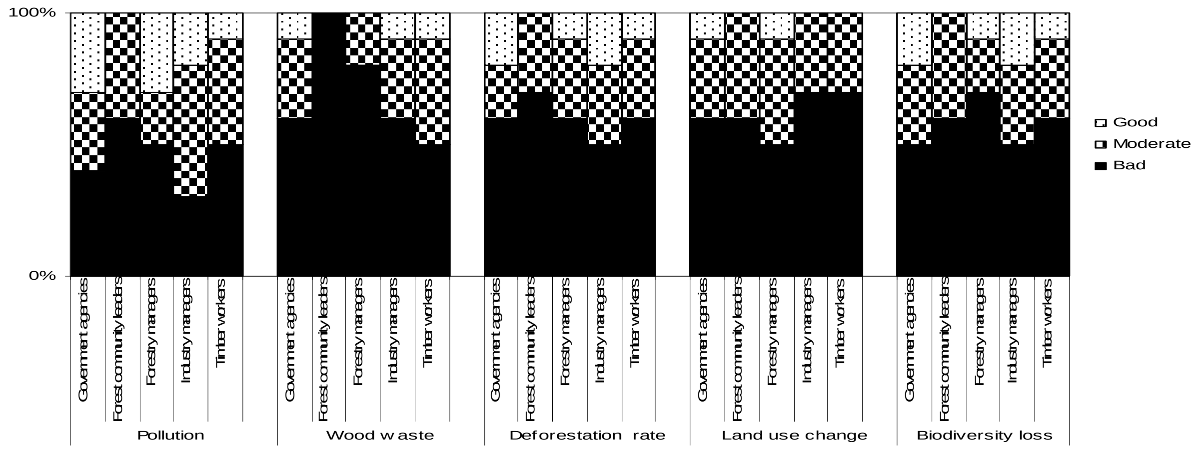

Figure 2.8: Summary of average response of selected stakeholders on the environmental impact of the sustainability of the timber sector in Ghana

The wood waste impact measures the wood materials left from timber harvesting and production process in the timber sector. It was considered as bad by 70% of the respondents. The additional interviews specifically pointed to the lack of knowledge and technology to recycle the large amount of waste into meaningful wood product. The central region has a serious problem with wood waste according to Figure 2.8 and also this was attributed to the lack of technology and investments.

The deforestation impact measures how respondents think about the amount of forest area lost or removed as a result of activities in the timber sector. The majority of respondents, 60%, considered deforestation as bad. They see that almost all the forest is gone, which agrees with the trends seen in the satellite imagery shown in Figure 2.9. Excessive logging coupled with illegal chainsaw operation was identified as some of the major causes of this forest loss. The most affected region as a result of the forest lost is the Central region (Figure 2.8).

The land-use change impact measures respondent perceptions of changes of the physical space and surface topography of the natural forest. Land use changes were considered by 60% of the respondent as bad. These bad land-use changes were cited to have led to changes in biotic conditions and the microclimate (humidity, wind, nutrients, and drought). According to Table 2.0, Western and Ashanti regions happens to be the most affected land-use change regions because they have the greatest regional influence in timber production in the timber sector of Ghana. This is illustrated in the landsat satellite image for Bobiri Forest Reserve (Ashanti Region), Figure 2.9.

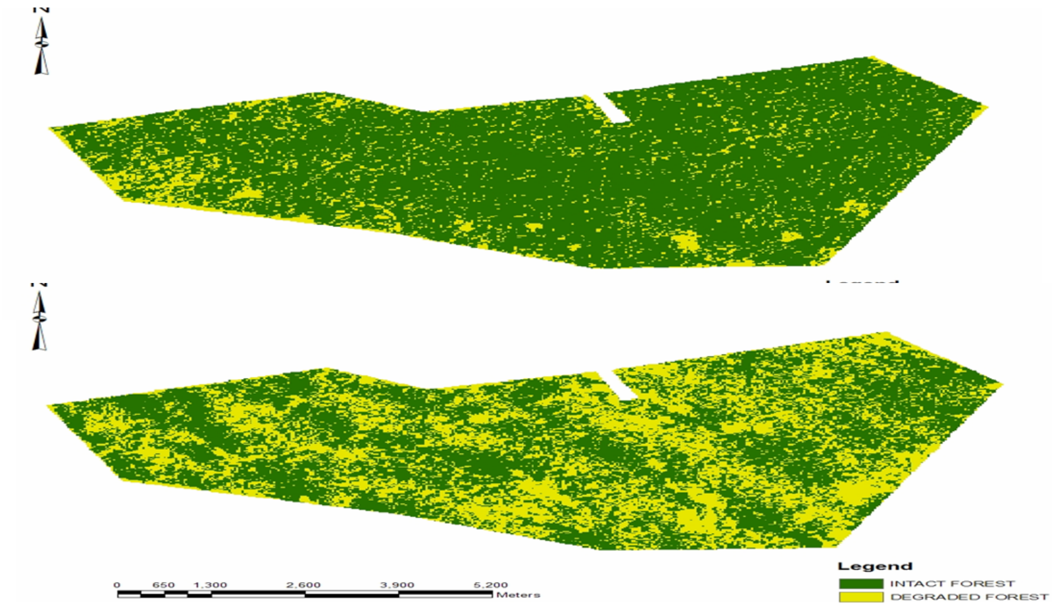

Figure 2.9: The Landsat satellite image for Bobiri Forest Reserve (Ashanti Region), showing the degradation of the Bobiri Forest Reserve in 1986 (top) and 2007 (bottom). The forest Area in 1986 is 5826 ha and 978 ha in 2007. 4847 ha has been lost in 21 years.

Biodiversity loss impact measures changes in the number, variety and the variability of living organisms in the natural tropical forest. According to the survey conducted, 58% of the respondents indicated biodiversity loss in the timber sector as bad. This bad biodiversity loss was cited to have led to the virtual depleting of the number of major traditional commercial timber species, animals species and plants species in the natural tropical forest. All selected stakeholders across all forest regions cited biodiversity loss in the timber sector as bad (Table 2.1). This biodiversity loss is slightly more pronounced in the Ashanti region as shown in Figure 2.8.

Discussion

This article gives an overview of the sustainability situation of the timber sector, i.e. forestry and timber industry, in Ghana. Sustainability indicators for economic, social and environmental impacts were assessed by using a structured closed-ended questionnaire. This structured closed-ended questionnaire was administered among a carefully selected sample of fifty stakeholders, two times five different stakeholders for each of five selected forest regions in Ghana. The survey was supplemented by in-depth personal interviews. This study has yielded unique insight in the relation between the formal and informal timber sector and how their competition influences the sustainability situation in Ghana. These insights are discussed in this in the light of existing literature that usually relate to the formal sector only.

Figure 2.10 summarizes the results for all sustainability indicators assessed by means of our questionnaire. The performance for all indicators is moderate to bad, except for the 'market impact' indicator that expresses the availability of wood product for a fair price to the local Ghanaian market. In contrast to what this may suggest, however, the local wood supply by the formal timber sector does not meet the local market demand.

The negligence of the local market by the formal timber sector has, amongst others, resulted in illegal chainsaw activities to supplement the local demand for wood. The majority of workforces in the informal timber sector are self-employed, e.g. as illegal chainsaw operators, because of the sluggish growth of the formal timber sector employment (Table 2.0). The informal sector activity is not properly managed and regulated and is very pervasive. This pervasiveness has created a sustainability gap that is expected to be widened if the activities of the informal timber sector are not better managed and regularized. This sustainability gap poses a potential risk to the timber sector in Ghana.

The formal timber sector activity is supposed to be managed and regulated better than the informal sector. Also the formal sector is in vain, however, drives the moderate to bad performance for all sustainability impact indicators other than the "market impact" indicator. The personal interviews and other sources cast a light on the intertwinement of all social, economic and environmental impacts that sometimes simultaneously act both as causes and consequences. This complexity, that hampers the sector's sustainability, is rooted in the competition between the informal and formal timber sector for timber raw material supply.

The competition between the formal and informal timber sector for wood supply from available forest reserves is a clear example of the tragedy of the commons as proposed by Hardin (1968). The short-term self-interest of each stakeholder will lead to complete deforestation in 2025 at the present rate of exploitation (Eshun et al. 2010a).

In the quest to control the rate of exploitation by the illegal chainsaw activities, the formal timber sector was tasked by the forest and wildlife policy in 1994 to manufacture wood products for both local and international markets in accordance with a 80% export and 20% local market rule (FPIB 1996). Despite this rule, there presently still is an obvious lack of the formal timber sector to meet the local demand of lumber. The informal timber sector specifically illegal chainsaw activities have become even more dominant in meeting the present needs of the local market (Inkoom 1999, Hutchful 2002, Sarfo-Mensah 2005, Amoah et al. 2009).

The insufficient supply of wood by the formal timber industry can be considered as a policy failure in the timber sector of Ghana. This policy failure stems from two major reasons.

Firstly, the objective of the 1994 forest and wildlife policy in Ghana was to promote the development of forest-based industries that viably and efficiently utilize timber and other products from forest resources to satisfy local and international demand for competitively-priced quality products (FPIB 1996, Inkoom 1999, Hutchful 2002, Sarfo-Mensah 2005, Marfo 2010). This was translated into the 20% local and 80% wood export rule, which was supposed to regulate the local and international wood supply, but dramatically failed to meet the actual local wood demand. The 20% local lumber supply by the formal timber sector was equal to 150,000 m^3 annually when the policy was enacted, while the annual local demand for lumber was estimated to be 450,000 m^3 (Marfo 2010). The formal timber sector was apparently not able to supply the local market, because of forestry concessions and lack of investment and technology challenges. This created a shortfall of 300,000 m^3 in the timber sector. This supply gap persisted and continued to be filled by the informal timber sector (illegal chainsaw operators).

Secondly, amidst concerns for environmental conservation and management of the forest resources, the Timber Resources Management Act was enacted in 1997 as one of the several measures designed to reverse deforestation in Ghana (Kufuor 2004). This policy also failed because the negative trends of deforestation after the introduction of this policy was so alarming (Kufuor 2004, Marfo 2010). According to Kuffuor (2004), the informal timber sector perceived it as motivated by the formal sector and a design to conserve the forest by regulating and eliminating their activities in the sector. The high incidence of illegal chainsaw activities in the timber sector may be attributed to this policy failure feedback. According to Hardin (1968), in a common resource, multiple owners are each endowed with the privilege to use a given resource, and no one has the right to exclude another. The tragedy of the common resource arises when too many owners hold such privileges of use and this is prone to over-exploitation. Therefore policies should not be seen to favour a particular group of people in the timber sector.

According to the personal interviews conducted, some stakeholders specifically representatives from the formal sector perceived the rapid destruction of the natural tropical forest as the Government inability to enforce its sustainability policies. Our analysis of the current situation in the timber sector partly support this stakeholders view, but likes to put the emphasis on another important dimension. Major policy interventions to enhance sustainability of the Ghanaian timber sector should focus on all key stakeholders. That is, they should be motivated by the public interest rather then guided by formal interests only. The latter is presently at stake and in our opinion an important reason why sustainability policies in the timber sector of Ghana are not working.

The informal and formal timber sectors should understand that their present competition is irrational in the long-term. Continuing the unstrained exploitation of the common forest resources will ultimately completely deplete and render the resource valueless. In this process, wider society but also the responsible stakeholders will in the end bear the costs of their irrational decisions. This tragedy of the common (Hardin 1968) need to be reversed to achieve environmental sustainability in the timber sector. There are several necessities and options.

Firstly there is an urgent need to formalize the informal timber sector, especially the illegal chainsaw operators, by way of regulating their activities and involving them in a stakeholder's discussion about the use and sustainability of the natural forest resources.

Secondly, the policy to ban informal timber sector activity (i.e. illegal chainsaw operation) has on the contrary greatly contributed to the aggressive exploitation and unsustainable use of the forest resources in Ghana. Policy makers in the timber sector must understand that the formal suppression of an activity does in practice not necessarily curb the over-exploitation of a resource and hence sustainability. The informal timber sector should not be seen as enemy, but as a partner in achieving sustainability of the natural forest resources. The forest resources can best be managed collectively by other stakeholders particularly the local communities and the government. Governments in Africa especially Ghana have managed forest resources without the involvement of the local communities and other stakeholders at the expense of sustainable development. This development has supplied rents to powerful interest groups in the timber sector as a means of regime survival. This is the time the role of governance in the timber sector management is clearly defined to sustain the forest resources. There is no incentive for environmentally friendly legislation by government. Government should rather provide a legal framework for other stakeholders specifically the local communities to assume greater control over the forest resources at the expense of national bureaucracy. This approach will go a long way to sustain the forest resources in Ghana.

Thirdly, another option may be to circumvent state involvement in the timber sector in Ghana by an internal code of practice to which all stakeholders commit. This internal code of practice will enable disputes in the Ghanaian timber sector to be resolved in special courts instead of by legal rules enforced by the state. Lisa Bernstein (1992) advocated that for the diamond industry in the United State of America. The diamond industry has systematically rejected state-created law. In its place, key stakeholders have developed an elaborate, internal set of rules, complete with distinctive institutions and sanctions, to handle disputes among sector members. The diamond industry, as it has been traditionally organized, is now able to make and, more important, enforce its own rules.

A fourth option available to policy makers in the timber sector is to privatize the forest. Over-exploitation of the commons is often argued to be a consequence of the absence of private property rights (Quentin Grafton et al. 2000). Private property in environmental resources aims to change the behaviour of formal and informal timber sector that seek to exploit the common forest resource. According to Kuffuor (2004), property rights in natural resources promote economic efficiency in resource utilization. That is because ownership creates incentives for formal and informal sectors to internalize any external problems that may arise. In effect, privatization would guarantee responsible timber operations, as formal and informal sectors would have an incentive to protect their own natural resources.

Fifthly, the survey and personal interviews point to the competition for raw material supply as the root for, at the same time consequence of other sustainability impacts in the timber sector. This suggests that there is an urgent need to also look at those other economic, social and environmental impacts. Economic development policies in formal timber sector of Ghana have mainly promoted production and export of primary wood products instead of value added wood products. This largely results from a lack of competent production management skills, technology and relevant investments (Table 2.0).

The inability to invest in technological improvements further contributes to the enormous wood wastage. This growing wood wastage accelerates deforestation and land use changes, and consequently reduces employment possibilities and increases pollution

(Table 2.0). The timber sector must match their choice of technological investment to its sustainability policies, local needs and conditions, and its obvious constraints. Relevant technology investments will enable the timber sector to produce efficiently, add value, thrive and grow economically, provide more employment opportunities and export to, as well as compete in, the global economy. It is therefore critical to substantially raise productivity levels within the boundaries of sustainability and value addition.

The lack of sustainability of the formal timber sector expresses in numerous negative social impacts such as human right violation, corruption, occupational health and safety issues and unemployment in forest fringe communities (Table 2.0). These communities are highly dependent on the sector industry, because timber is an integral part of their local economy. The lack of economic and social responsibility of the timber industry has contributed to the inability of the sector to achieve environmental sustainability. The interaction between economic and social sustainability indicators are crucial and should be optimized within environmental constraints (that may vary among regions and communities in time).

These foregoing developments constitute a setback to the sustainable management of timber sector. Efforts to improve timber sector's sustainability can only be effective if done correctly. The order and transparency of reforms in the timber sector is vital to the successful recovery and sustenance of the tropical natural forest base. This also points to the fact that, if major policy interventions are not put in place the timber sector will not be sustainable.

The survey results agree with trends seen in the literature and satellite imagery (Figure 2.9). However, the survey adds more relevant local and stakeholders' information. This additional information is needed to sustain the timber sector in Ghana. Achieving sustainability in the timber sector is not a simple task, but the ultimate fate is with all stakeholders. They need to make the actual decisions to either protect the tropical natural forest base or allow the degradation to continue. The insights for a better understanding that we have been presented, shows that the sustainability of the timber sector in Ghana essentially lies in their hands.

Conclusion

This overview of the timber sector in Ghana starts from the urgent attention required for the state of natural tropical forests in Ghana and their rate of destruction. Major policies implemented in the Ghanaian timber sector have greatly contributed to the aggressive exploitation and unsustainable use of the forest resources in Ghana. The intended control and suppression of informal sector activity did not curb over-exploitation of the resource and hence sustainability.

This chapter used a closed-ended questionnaire and supplementary interviews to obtain insight in the role of the formal and informal timber sector in economic, social and environmental impact in Ghana. The valuable insights gained are synthesized with existing literature and other sources that usually focus on the formal sector only. The synthesis provides a comprehensive knowledge base which can be deployed by the various stakeholders for informed decision-making on the sustainability of the timber sector in Ghana. Whichever policy options may emerge, the information contained in this study can provide a way forward for improved decisions on the sustainability of the timber sector in Ghana.

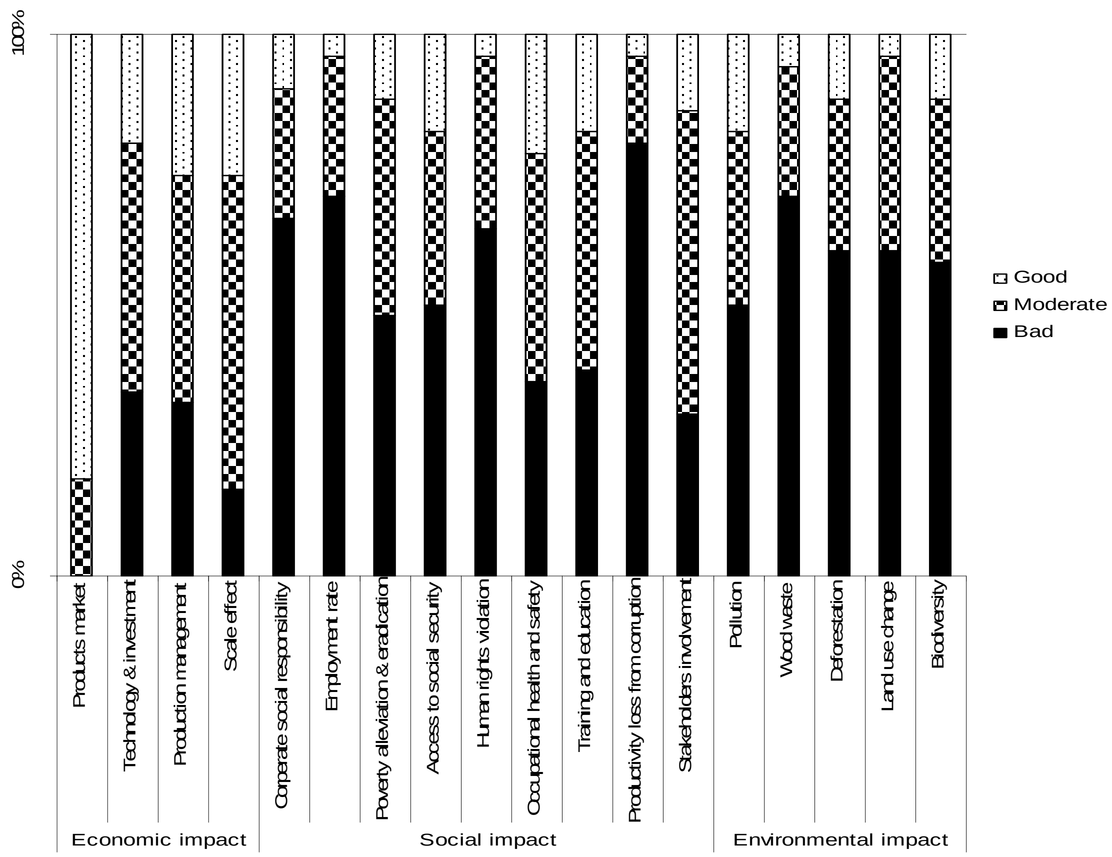

Figure 2.10: Summary on share in total percent of average response on overview of the sustainability of the timber sector in Ghana

Chapter 3: Inventory analysis of the timber industry in Ghana

This Chapter was presented at 19th Annual SETAC Europe meeting: Protecting ecosystem health: facing the challenge of a globally changing environment: from 31st May - 4 June 2009, Goteborg, Sweden.

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Chapter 3: Inventory analysis of the timber industry in Ghana

Abstract

Background, aim, and scope: The timber sector, i.e. forestry and timber industry, plays an important role in the socioeconomic development of Ghana through timber products export. Timber production in this sector is associated with increasing environmental burdens in terms of use of materials and energy, production of emissions and waste, and land use changes. The purpose of this study was to compile a comprehensive Life Cycle Inventory (LCI) to identify the most dominant environmental pressures for five major production lines in the timber industry, and to evaluate the influence of the choice of the functional unit on the results (1m^3, 1kg and 1euro). LCA's of wood typically base their functional unit on volume, but mass or money may be more appropriate for the rather different products considered in this study.

Materials and methods: The LCI covers five timber production lines, namely air dried lumber, kiln dried lumber, plywood, veneer and furniture parts. Three functional units were used for this study to identify the most appropriate basis for a fair comparison of the different timber products (functional units were 1m^3, 1kg and 1euro). Questionnaires were administered to thirty selected companies in Ghana. These companies provided data about their material uses, energy requirements, and waste production for their operations from 2000 to 2007. The collected data were first converted into total annual average values, and next extrapolated to reflect the national average data for all one hundred and four active companies. Finally, these data were expressed per functional unit for each of the five product lines on the basis of their production outputs (in volume, mass or money according to functional unit applied). Forest land used changes data was taken from the Ghana Timber Industry Development Division. Emissions for the several activities were taken from literature.

Results and discussion: Land use change for timber production in Ghana between the estimated periods turned out to be 34.0 x 10^3 ha per year, which will lead to complete deforestation in the year 2023 if continued. The total energy consumed by the timber sector per year was estimated at 1.9 x 10^9 MJ per year. The results showed that CO_2 emissions by the timber sector activities per year accounted for 745 k tons per year and dominate overall greenhouse gases emissions in the timber sector (changes in carbons storage related to land use changes not included). Wood waste by the timber sector accounted for 0.8 million m^3 per year. The enormous wastage of wood contributes enormously to the rapid depletion of the country's timber resources. The choice of the functional unit influences inventory results. The money-based functional unit, which also seems more appropriate for the different products considered, favors the value-added. Value-added products with strict sustainable forest management policy hold a promising future in terms of sustainability for the timber industry in Ghana.

Conclusions: This study has yielded good quality primary data unique for LCA research in Africa. This will enhance LCA approaches in Ghana, and allows here identification of the main environmental pressures and their dominantly contributing processes in the timber sector. Land use changes due to forestry form a critical issue and require urgent attention. The chosen functional units' plays a crucial role in the environmental comparison of production line in the timber sector in Ghana.

Recommendations and perspectives: A comprehensive and transparent inventory for the timber industry provides the industry with an overview of areas in which material and thus economic savings can be made for the good of both environment and the industry finances. Good data keeping in the Ghanaian timber industry will help to build the

required research capacity to develop local familiarity and competence in LCA techniques and applying these techniques will help to further certify tropical timber international markets.

Keywords: Functional units • Ghanaian timber • Inventory Analysis • Life cycle inventory (LCI) • Tropical wood

Background, aim, and scope

The timber sector, i.e. forestry and timber industry, is important for Ghana because it provides jobs and incomes for numerous local communities, and significantly contributes to Ghana's foreign exchange earnings through timber products export. Since 1990 up to now timber production is Ghana's fourth biggest foreign exchange earner (FOSA 2001, Lebedys 2004, Odoom 2008). In 2004, Ghana earned €170 million from 0.5 million m^3 of wood product export (Oliver and Fripp 2005). Figure 3.0 gives an overview of main products and their share in total timber output. The timber production in this sector is associated with an increasing environmental burden in terms of use of resources, and production of emissions and waste (Ghana Gazette 2005). Recently, the concern about environmental impacts has gone beyond relying on existing national regulation because international markets are increasingly demanding environmentally sound products.

Analyzing the environmental performance of the timber sector is complex because of a variety of environmental, political, social and culture dimensions. This requires a more integrated approach in identifying ways to access and reduce the total environmental burden of the timber sector. Life cycle thinking has become a key focus in environmental integrated product policy and an effective integration of life cycle thinking in the timber sector is considered as a critical success factor for more sustainable industrial models (Ometto et al. 2006, Swarr 2006, Huang et al. 2007, Sundkvist and Finnveden 2007, Lilja and Liukkonen 2008, Rau and OuYang 2008). Therefore, analyzing the environmental performance of the timber sector provides an effective first step to develop, implement and improve its environmental management.

Life Cycle Assessment (LCA) is a standardized method (ISO 14044 2006) to comprehensively assess and evaluate the complex environmental burdens associated with the manufacturing of a product from resource extraction to end of life (Berg 1997, Papatryphon et al. 2004, Milota et al. 2005, Puettmann and Wilson 2005, ISO - 14044 2006, Nebel et al. 2006, Swarr 2006, Matheys et al 2007, Michelsen 2007, Rivela et al. 2007, Schweinle 2007, Werner 2007).

This method was used for assessing the environmental impact of the timber industry in Ghana and identifying effective environmental improvement options. This paper focuses on the first and second step in LCA that is often referred to as life cycle inventory (LCI). The LCI here covers the five major Ghanaian timber products: air dried lumber, kiln dried lumber, plywood, veneer and furniture part. These products constitute about 90% of the total timber products export in Ghana.

Most existing LCA studies of the timber sector focused on a single production line, such as plywood production (Wilson and Sakimoto 2005), sawmill production (Milota et al. 2005), forestry e.g. (Johnson et al. 2005, Lippke et al. 2005), veneer production (Wilson and Dancer 2005). The functional unit in these studies was usually defined as 1 m^3 of product produced. This study focuses on a combination of production lines to achieve a higher level of integration of assessing environmental performance in the timber sector in Ghana. The products from these production lines obviously are different in the service they provide, and these different services are expected to be insufficiently expressed by the usual functional unit of 1 m^3 of product produced. We therefore selected two additional functional units, one defined as 1 kg of product produced and the other as 1 euro of product produced (all products and functional units calculated at the same moisture content).

LCA has not received much attention from the research communities in Ghana. The method is still unknown, and data relevant for Ghana's timber sector are limited available. Most existing LCA studies for the timber sectors focus on plantation forestry as a source of raw material to the timber industry. This study focuses on natural tropical forests for resource extraction. It is important to note that LCI data on products from tropical timber is scares and limited in quality (Werner 2007). This study is therefore expected to generate LCI data for natural forestry in specific, and to provide an improved insight in the usefulness of the LCA tool for evaluating environmental policies in Ghana.

The objective of this study was to compile a comprehensive LCI to identify the most dominant environmental pressures in terms of material resource usage, emissions, energy use, waste production and land use change, and to evaluate the influence of the choice of the functional unit for five major product lines in the timber sector in Ghana. The five major timber products are; air dried lumber, kiln dried lumber, plywood, veneer and furniture parts. This LCI study is intended for use amongst stakeholders and policy makers in deciding for the future of the timber industry in Ghana. It is my hope that this study will contribute to enhance LCA use and research in Africa.

Materials and methods

System description

This study was carried out in accordance with ISO 14044 (2006) that specifies requirements and guidelines for conducting LCA. Figure 3.1 provides the process flow and system boundaries of timber sector in Ghana. It represents the linkages between subsystems, i.e. the forestry subsystem and the five product lines in the timber industry subsystem, and their unit-processes that together make up the product system or life cycle of products from Ghana's timber sector.

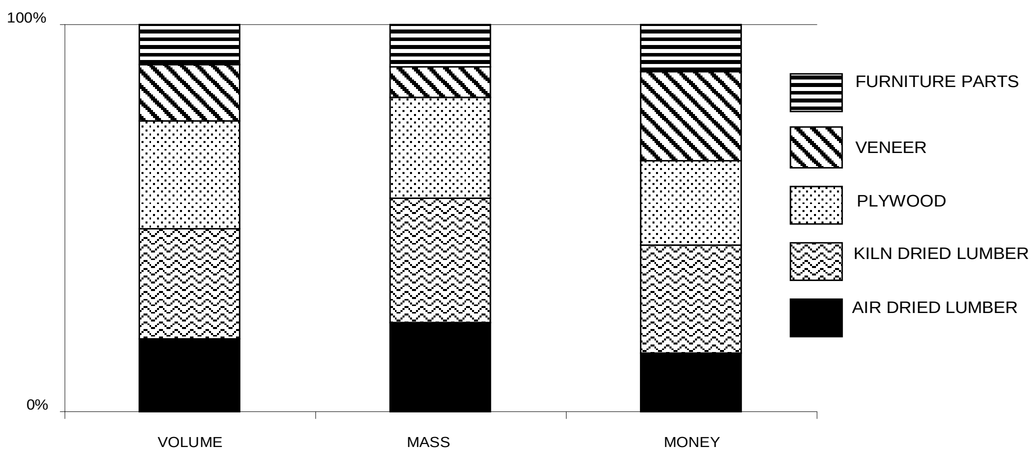

Figure 3.0: Share of wood products in total output of Ghana timber sector from 2000 to 2007 according to Volume (m3), mass (tons) and money (€)

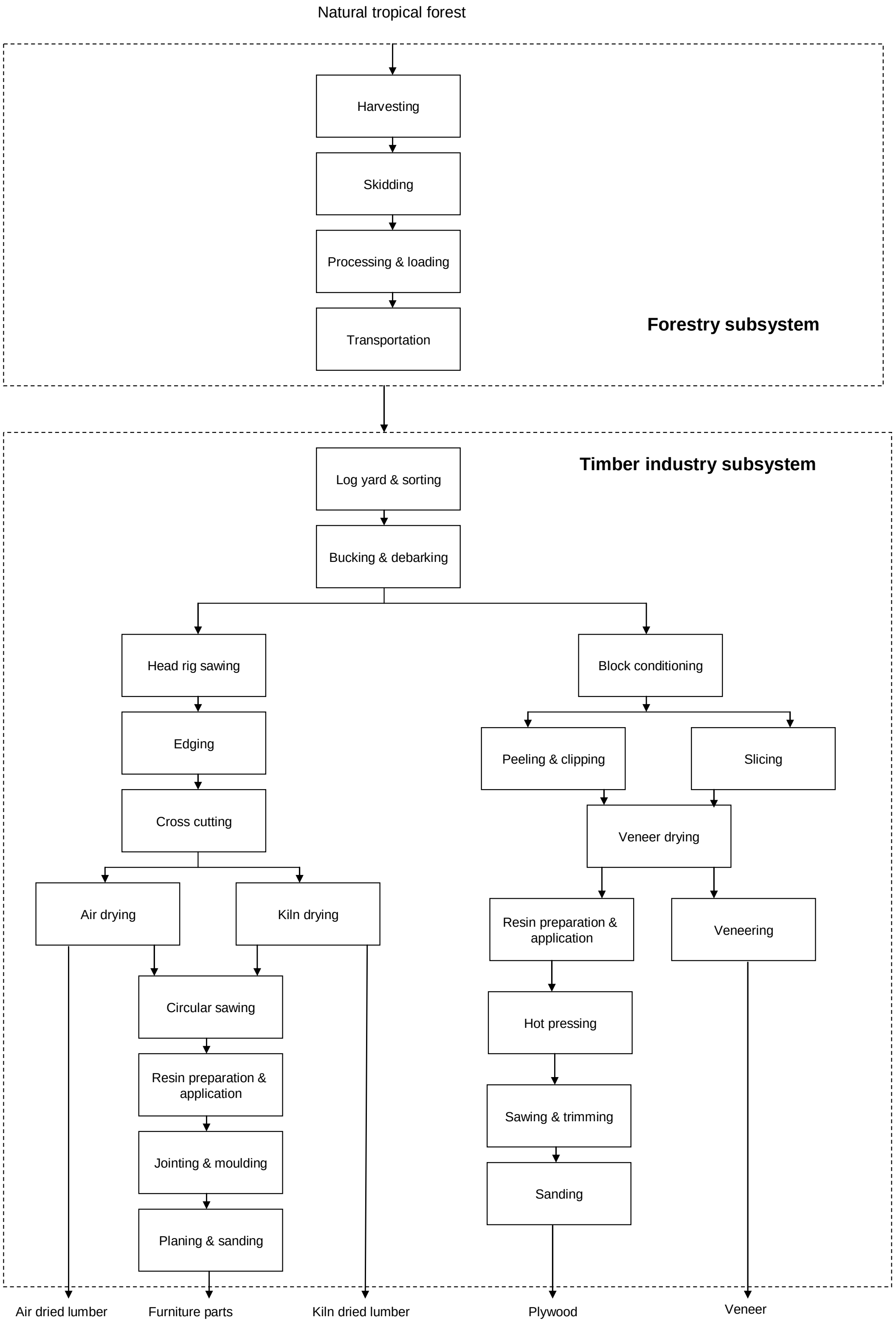

Figure 3.1: Flow chart of the unit-processes in the forestry and timber industry subsystems of the timber sector in Ghana

Data collection procedure for forestry subsystem

Natural tropical forest is the main source of timber supply to the timber industry in Ghana. It accounts for about 80% of the total input (Ghana Gazette 2005). Forest plantation is now being developed in Ghana, but yet of relatively minor importance for Ghana's timber sector, and therefore not included in the LCI. The main activities in forestry (logging) subsystem are represented in Figure 3.1. LCI for these activities focused on the material use, energy use, emissions of pollutants, and land use changes. Except for land use, data collection for these forestry activities was taken together with data collection for the timber industry. That is, because all timber companies in Ghana have forestry department attached to them that deal with all forestry issues related to the input to their own company activities. The forest land used changes data source was taken from Ghana Timber Industry Development Division (2006). Land degradation by deforestation and desertification is a major problem caused by the timber sector.

Data collection for timber industry subsystem

A selection of 30 timber companies was made of one hundred and four (104) active timber companies in Ghana. Two sampling techniques were adopted. The first state stratified sampling was based on three market orientations of companies. According to Forestry Product Inspection Bureau (1996), the market orientations of the thirty (30) selected companies consist of fifteen (15) companies providing 100% export market, eight (8) companies 100% domestic market, and seven (7) companies mixed (Table 3.1). The second state stratified sampling was based on the log input category of the companies. The total of thirty (30) selected companies consists of twelve (12) small, eight (8) medium, six (6) large and four (4) extra-large ones. Each company covers one product line only. This means that companies with more than one product line were excluded from the sample. This was done to enhance data processing.

Regional distribution of companies was a consideration for the selection of samples for the study. Questionnaires were administered to the thirty (30) selected companies in Ghana and they provided data about the inputs and outputs to their activities for resources, material uses, energy requirements, and waste production from 2000 to 2007.

Records keeping in Ghana do provide data in lump, and thus not according to unit-processes in the forestry subsystem and for the sawmilling and ply-milling and furniture processes in the timber industry subsystem (see Figure 3.1). These lumped data were allocated to the five product lines on the basis of the production outputs (in volume, mass or money according to functional unit applied). Process-specific data were provided for the kiln drier and for resin preparation and application. The data of five companies were considered of insufficient quality. The collected data for the other twenty five (25) companies were converted into total annual average values, and for a fair comparison on the national level extrapolated to reflect the national average data for all one hundred and four (104) active companies. The sawdust, off cuts and barks are treated as wood waste in the Ghanaian timber industry unless they are used for fuelling in-house boilers. No allocation rules were needed since the companies were selected to cover one product line only and therefore the level of process detail was sufficient to avoid multiple output processes.

Data relevant for Ghana's timber sector were limited available. Additional interviews were done to check data quality and to ascertain which processes were specifically covered by lumped data. Some assumptions had to be made. For instance, the average distance between the forest sites and the wood production companies was taken to be 500 km (in reality the distance varies from 200 to 500 km).

Table 3.0: Sampling scheme of 30 selected companies used for data collection in the timber sector in Ghana

Log input - volume criteria	**Market orientation criteria** 100% Export	Mixed (50-50%)	100% Domestic	Total
Small V< 7,000 m^3 per annum	5	4	3	12
Medium 7,500<V<20,000 m^3 per annum	4	2	2	8
Large 20,000<V< 40,000 m^3 per annum	2	2	2	6
Extra large V> 40,000 m^3 per annum	4	0	0	4
Total	15	8	7	30

Calculation of emissions in the timber sector

Emission inventory data were not available for the timber companies visited in Ghana. We used the emission factors in Table 3.1 to calculate selected emissions as function of production volumes of a particular product line as illustrated in equation 1. We made the resulting emissions as local as possible by calculating them as function of production volumes as provided by the survey (see Table 3.3). In this context, the production capacities were virtually thought of as an activity (Jawjit et al. 2006). This study took into account emissions contributing to global warming, acidification, smog, and human toxicity. The selected emissions are CO_2, CH_4 and N_2O for global warming; SO_2 and NO_X for acidification; CH_4, NO_X, NMVOC, CO for smog; NO_X and SO_2 for human toxicity. The results of emission calculations were expressed in ton of pollutant either emitted or generated from a product line of the timber sector per year (ton per year) as illustrated in Table 3.4.

$$\text{Emission} = \text{Activity} \times \text{Emission Factor} \qquad (1)$$

Functional unit

Volume is commonly used as output unit in timber companies, and the functional unit for LCAs of timber products is usually accordingly defined as 1 m^3 of product produced (Milota et al. 2005, Wilson and Sakimoto 2005). A functional unit provides the reference to which the environmental inputs and outputs of a product system are related (ISO - 14044. 2006).

Table 3.1: Emission factors as used in equation (1) for the calculation of the emissions from timber sector in Ghana

Activity area	Compound emitted	Emission factors	Unit	Reference
Forestry subsystem				
Harvesting activities and transportation of log to company (Diesel used)	CO_2	3150.00	g / kg fuel	Schwaiger (1995)
	CO	15.00	g / kg fuel	IPCC (1997)
	N_2O	0.02	g / kg fuel	Schwaiger (1995)
	CH_4	6.91	g / kg fuel	Schwaiger (1995)
	NO_X	50.00	g / kg fuel	IPCC (1997)
	NMVOC	6.50	g / kg fuel	IPCC (1997)
	SO_2	20.00	g / kg fuel	IPCC (1997)
Timber industry subsystem				
Saw milling drying of wood	CO_2	920.00	kg/m^3 of wood	USEPA (2003)
	CO	2.55	kg/m^3 of wood	USEPA (2003)
	VOC	1.65	kg/m^3 of wood	USEPA (2003)
	SO_2	0.12	kg/m^3 of wood	USEPA (2003)
	NO_X	2.55	kg/m^3 of wood	USEPA (2003)
Boiler activities Biomass combustion	CO_2	110.00	ton/TJ	IPCC (1997)
	CO	4000.00	kg/TJ	IPCC (1997)
	CH_4	30.00	kg/TJ	IPCC (1997)
	N_2O	4.00	kg/TJ	IPCC (1997)
	NMVOC	250.00	kg/TJ	IPCC (1997)
	NO_X	100.00	kg/TJ	IPCC (1997)
Veneer drying	CO_2	920.00	kg/m^3 of wood	USEPA (2003)
	CO	2.55	kg/m^3 of wood	USEPA (2003)
	VOC	1.65	kg/m^3 of wood	USEPA (2003)
	SO_2	0.03	kg/m^3 of wood	USEPA (2003)
	NO_X	0.12	kg/m^3 of wood	USEPA (2003)
				USEPA (2003)
Diesel used	CO_2	3150.00	g / kg fuel	Schwaiger (1995)
	CO	15.00	g / kg fuel	IPCC (1997)
	N_2O	0.02	g / kg fuel	Schwaiger (1995)
	CH_4	6.91	g / kg fuel	Schwaiger (1995)
	NO_X	50.00	g / kg fuel	IPCC (1997)
	NMVOC	6.50	g / kg fuel	IPCC (1997)
	SO_2	20.00	g / kg fuel	IPCC (1997)

It defines the service of the studied products in relation to user requirements and is typically expressed as the unit service for a specified period of time. The functional unit must include both a qualitative and quantitative description of the products service provided to the user so that the product can be compared on a fair basis. Such functional unit is difficult to define here as the properties and services differ significantly between the wood product lines covered in this study. A generic functional unit is nevertheless necessary for comparability of LCA results. The different services are expected to be insufficiently expressed by the usual functional unit of 1 m^3 of product produced. We therefore selected two additional functional units. One defined as 1 kg of product produced and the other as 1 euro of product produced. The results for all functional units and products are expressed at the same moisture content of 12%. The inventory results for the five timber products in this study were thus compared on a $kgton^{-1}$, kg m^{-3} and kg $€^{-1}$ output basis.

Results and discussion

The results of the inventory study were first extrapolated to total inputs and outputs of the Ghanaian timber sector to also have a basis for fair comparison on the national level. Next they were analyzed in accordance to the selected three functional units for a fair comparison at the product level (i.e., environmental inputs and outputs expressed per volume, mass and money unit of timber product). Results are calculated for each of the five different product lines of the timber sector in Ghana (air dried lumber, kiln dried lumber, plywood, veneer, and furniture parts).

Forestry subsystem – land use inventory

Inventory results for material and energy use are presented in the next section as these were taken together with the timber industry subsystem. This section focuses on land use changes. The natural forest for timber production between 1989 and 2002 decreased according to official numbers by 442.0 x 10^3 ha as illustrated in Table 3.2. This gives a yearly degradation of 34.0 x 10^3 ha. If this degradation trend continues in the same speed, then the total production area will be reduced to 515.0 x 10^3 ha by the end of 2008. All the forest will have been gone by the year 2025.

The World Bank (2006) estimates Ghana's deforestation in 2003 at around 65.0 x 10^3 ha per year. This equals with an annual cost of degradation of around 3.5 percent of Ghana's Gross Domestic Product, together with habitat loss, species extirpation. Deforestation value according to World bank is almost doubling the deforestation value used in this study, because The World Bank (2006) also includes illegal logging and mining activities in some forest reserves. Degradation of the forest resource is taking place for both off-forest and on-forest reserve. Off-forest reserve refers to unmanaged forest, where loss has arisen from the mix of expansion of farming (especially cocoa) and illegal demand of timber for informal timber sector industry. On-forest reserve refers to managed forest, where degradation has also accelerated dramatically in the last decade, due to over-logging, encroachment, illegal logging, and bushfires. This study refers to the formal timber sector.

Timber industry – materials, energy and waste

The survey resulted in quantification of the combined use of materials and energy in the forestry and the timber industry (Table 3.3). The production and utilization of round wood between 2000 to 2007 was approximately 1.3 million m^3 of logs as input to, and approximately 0.6 million m^3 of timber products as output from the timber industry annually (see Table 3.3). Kiln dried lumber and air dried lumber production lines contributed with 0.5 million m^3 per year to enormous amount of wood waste in the timber sector. This is as a result of the low production recovery in the Ghanaian timber industry. Another notable source of wood waste occurs in the forest during timber harvesting. This wood waste is usually not recorded. The enormous quantities of waste per product line in Table 3.3 are therefore even an underestimate of the actual quantity of wood wasted in Ghana's timber sector.

Table 3.2: Land use inventory of natural forest for timber production from 1989 to 2002 in Ghana

Region	Total reserve area (10^3Ha)	Production forest (10^3Ha), 1989	Production forest (10^3Ha), 2002	Production forest (10^3Ha/yr)
Ashanti	384	235	126	8
Brong Ahafo	264	202	126	6
Central	111	123	73	4
Eastern	154	88	70	1
Western	701	513	323	15
Total	1,613	1,161	719	34

Source: (TIDD 2006)

One factor that is contributing enormously to the rapid depletion of the country's timber resources is wastage of wood during log processing in industry. As a consequence, the timber industry in Ghana produces a considerable amount of wood waste, in total estimated to be in the order of 0.8 million m^3 per year (excluding the above mentioned forest contribution from harvesting waste) as illustrated in Table 3.3. Wood waste thus constitutes a major setback to the sustainable management of the timber sector. Both avoidable and unavoidable wood wastes generated during harvesting and conversions are enormous. When pooled together, however, it can be used in the production of downstream processes such as wood based panel manufacturing in Ghana. This is regrettably not common practice in Ghana right now.

According to the energy inventory data in Table 3.3, the total energy consumed by the timber sector per year is estimated at 1.9×10^9 MJ per year. The main energy use was for drying wood products and is provided by combustion of in-house production waste in steam production boiler (no allocation rules were needed since the companies where selected to cover one product line only). This accounts for about 80% of the total energy consumed. The second energy users are the timber harvesting and transportation operations. Considering the energy usage by the various wood production lines, plywood production was the highest energy consuming process followed by the Kiln dried lumber.

Emission inventory of the timber sector in Ghana

Table 3.4 gives a summary of results for the greenhouse gases emission inventory of the timber industry in Ghana. This study shows that CO_2 emissions in the timber sector accounted for 745 K tons per year. This quantity dominates overall greenhouse gases emissions in timber sector. One might come to the thought that the emission of CO_2 from biomass combustion can be excluded from the greenhouse gas inventories, since this CO_2 is compensated through its fixation in the combusted wood derived from trees. IPCC (2006) recommends in the case of tropical forest, however, to specifically flag these emissions as an indicator for deforestation. Kiln dried lumber, Plywood and Veneer product lines contributed mostly to the CO_2 emissions. Not included in this study are CO_2 emissions from changes in carbons storage related to land use changes, e.g. emission from forest slashes, changes in below-ground biomass and organic carbon in soil. This is worth considering in future research work in Ghana.

Table 3.3: Average survey results for material and energy consumption, and waste production from 2000 to 2007 extrapolated to the average national yearly production of the timber sector in Ghana

	Units	Air dried lumber	Kiln dried lumber	Plywood	Veneer	Furniture parts	Total
Material input							
Logs	mln m^3/year	0.32	0.44	0.32	0.12	0.09	**1.29**
Urea formaldehyde	mln m^3 /year	0.00	0.00	0.05	0.00	0.03	**0.08**
Energy input							
Diesel (Timber harvest)	mln MJ/yr	20.00	29.00	19.00	7.00	10.00	**85.00**
Diesel (Transport)	mln MJ/yr	21.00	28.00	8.00	5.00	4.00	**67.00**
Electricity (Hydropower)	mln MJ/yr	19.00	26.00	19.00	7.00	5.00	**76.00**
Steam generation from boiler	mln MJ/yr	0.00	322.00	335.00	176.00	114.00	**947.00**
Biomass combustion	mln MJ/yr	0.00	249.00	291.00	148.00	89.00	**775.00**
Total	mln MJ/yr	**60.00**	**654.00**	**672.00**	**343.00**	**222.00**	**1,950.00**
Material & waste output							
Wood product	mln m^3/year	0.11	0.16	0.16	0.09	0.06	**0.58**
Sawdust	mln m^3/year	0.02	0.02	0.02	0.01	0.01	**0.08**
Off cuts	mln m^3/year	0.16	0.22	0.08	0.01	0.04	**0.51**
Barks	mln m^3/year	0.03	0.04	0.03	0.01	0.01	**0.12**
Peeler core	mln m^3/year	0.00	0.00	0.08	0.01	0.00	**0.09**
Total	mln m^3/year	**0.32**	**0.44**	**0.37**	**0.12**	**0.12**	1.37

Table 3.4: Results for emission inventory by products of the timber sector in Ghana (averaged over 2000 to 2007)

Products	CO_2 Ktons/ year	CH_4 tons/ year	N_2O tons/year	SO_2 tons/year	NO_X tons/year	NMVOC tons/year	CO ktons/ year
Air dried lumber	8	3	0	53	165	128	0
Kiln dried lumber	219	263	10	76	451	286	9
Plywood	223	147	8	50	366	173	9
Veneer	219	76	5	18	171	84	5
Furniture parts	77	25	3	25	148	62	3
Total	**745**	**514**	**26**	**222**	**1,301**	**733**	**26**

Comparison of functional units

For a fair comparison of different products, LCA data should be expressed in terms of a functional unit that appropriately describes the function of the product or process being studied. Careful selection of the functional unit to measure and display the LCA results will improve the validity of the study and the usefulness of the results. The different services provided by the 5 products in our study hamper the selection of one common functional unit suitably covering this. We therefore choose to express results in terms of volume, mass and monetary functional units. Figure 3.0 already showed that the share of the five major products in total output of Ghana's timber sector depends on the choice of units. Especially money clearly influences the share of veneer in total product output. Figure 3.2 shows that the choice of functional units also influences inventory results. The energy use, wood waste generation, emission and land use changes varies between the three chosen units for each of the 5 product lines. These differences come from the fact that the three functional units represent different product parameters that each only partly reflect the different services provided by each of the 5 products to the user. Relevance of product parameters can thus influence the choice of one specific functional unit for a particular product (kluppel 1998, Erlandsson and Borg 2003, Matheys et al 2007). Whereas veneer has the largest share in total financial output (see Figure 3.0), its inventory data makes the smallest contribution if expressed per money units.

The influence of the three functional units on the results are quantified in Table 3.5, and graphically represented in Figure 3.2. Comparing the results shows that the money-based functional unit favors the value-added products and veneer in particular. This in turn favors downstream processing of wood. Downstream processing of wood has the tendency with strict sustainable forest management policy to slow down the rate of exploitation of timber (ITTO 2005). High value products with strict sustainable forest management policy thus hold the potential to slow-down the pressure on tropical forest, and this holds a promising future in terms of sustainability for the timber sector in Ghana.

Conclusion and recommendation

LCI data for Ghana's timber industry were as to yet limited available. This study has yielded good quality primary data unique for LCA research in Africa. Only emissions were not available as primary data and therefore largely based on literature. All data used in this study was considered to be the best available data. Despite the fact that we did not perform a formal sensitivity analysis, the data obtained in this LCI clearly shows the difference between the product lines and therefore serve the purpose of the study.

Table 3.5: Summary of results for material consumption and waste production from 2000 to 2007 extrapolated to the average national yearly production of the timber sector in Ghana

		Units	Air dried lumber	Kiln dried lumber	Plywood	Veneer	Furni-ture parts	**Total**
Wood product	Volume	mln m^3 /year	0.1	0.2	0.2	0.1	0.1	**0.6**
	Mass	Ktons /year	44.0	54.0	61.0	24.0	19.0	**202.0**
	Money	mln € /year	31.0	60.0	46.0	64.0	24.0	**225.0**
Wood waste	Volume	mln m^3 /year	0.2	0.3	0.2	0.0	0.1	**0.8**
	Mass	Ktons /year	82.0	101.0	76.0	10.0	19.0	**288.0**
	Money	mln € /year	6.0	8.0	3.0	1.0	1.0	**19.0**

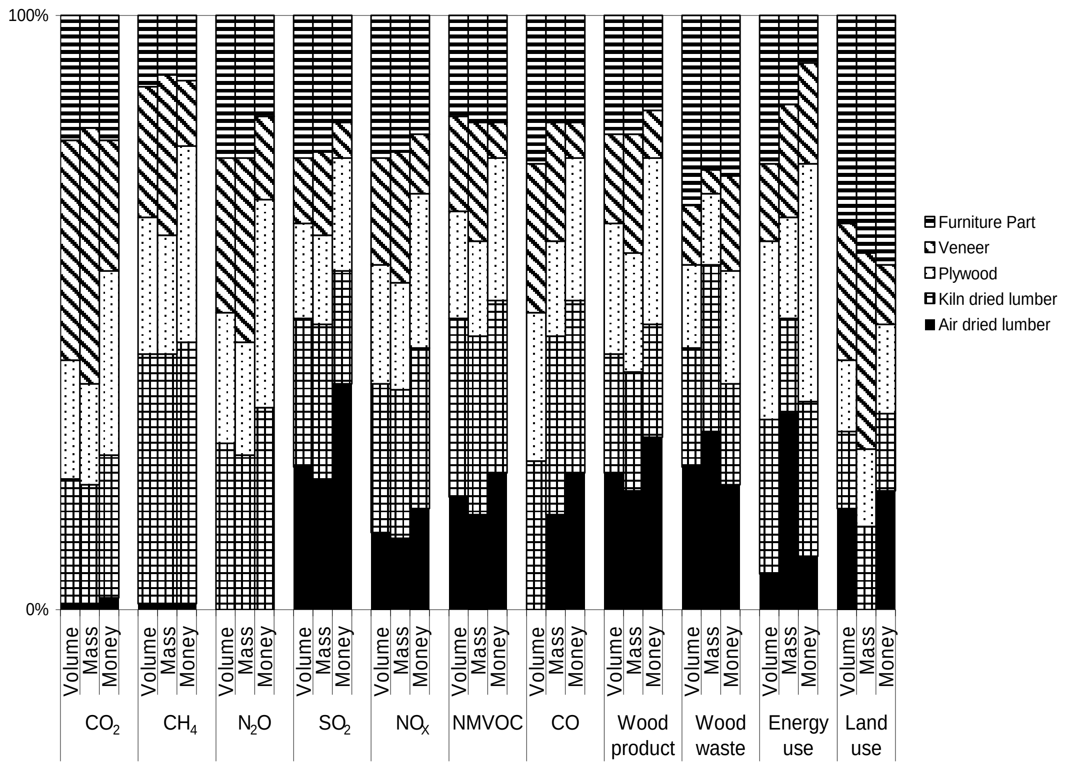

Figure 3.2: Influence of functional unit on LCI results for 5 major production lines in Ghana's timber sector

The main environmental pressures and their dominantly contributing processes have been identified in Ghana's timber sector (i.e., in its forestry subsystem and timber industry subsystem). It was found that enormous amounts of wood wastes are generated in the timber industry due to its low timber production recovery. Wastage of wood during timber processing in the timber industry therefore contributes enormously to the rapid depletion of the country's timber resources. CO_2 emissions were identified to dominate overall greenhouse gases emissions. Main contributors here are the kiln dried lumber, plywood and veneer production lines (changes in carbons storage related to land use changes were not included). Biomass combustion in steam production boiler, which was mainly used for drying wood products, accounted for the highest energy usage. Timber harvesting and transportation operations were the second largest energy users in the sector as a result of long timber transport distances. Land use changes were identified as a critical issue and require an urgent attention. If the degradation trend continues in the same speed, then the total forest production area would be gone by the year 2025.

The result of this study should preferably not be influenced significantly by the choice of one out of the three relevant functional units (kluppel 1998). The chosen functional units' shows to play a crucial role, however, in the environmental comparison of production lines in the timber sector in Ghana. Especially money has a clear influence, particularly on the results for the veneer product line. Veneer has the largest share in total financial output and makes the smallest contribution per money units.

The enormous wood wastage and land use changes in particular constitute a setback to the sustainable management of timber sector. Natural tropical forest resources are limited and the introduction of necessary constraints under sustainable forest management practices further reduces the availability of timber for harvesting. To meet the anticipated needs of the timber industry, greater emphasis must be placed on value added production. It is therefore critical to substantially raise productivity levels within the parameter of sustainability and value addition. This on its turn favors downstream processing of wood. Downstream processing of wood in combination with strict sustainable forest management policy has the tendency to slow down the rate of exploitation of timber (ITTO 2005). Value-added products with strict sustainable forest management policy thus hold the potential to slow-down the pressure on tropical forest, and this holds a promising future in terms of sustainability for the timber sector in Ghana.

All environmental inputs (land use, material use and energy) and outputs (emissions and waste) need to be included for identifying options to reduce the burden of Ghana's timber industry on the environment. This study has generated a unique database from tropical forest and the timber industry, which will enhance LCA approaches in Ghana. A full product LCA requires the combination of several units' process LCI data modules and this can be used as regional benchmarks to generate or assess industry, plant or new technology data to develop environmentally oriented decision support system and LCA tools. Having a common set of data based on a single protocol will improve the quality and consistency of LCA's in Africa.

Recommendations and perspectives

Compiling all inputs and outputs into a transparent inventory for the timber industry in Ghana, provides the industry with overview of areas in which material and thus economic savings can be made for the good of both environment and the industry finances. It also makes it possible to get an overview of whether inputs could be substituted by less polluting materials. This is where life cycle thinking plays a major role in product policy development for a future sustainable industry.

LCI data of good quality and representative for Ghana's timber sector has become available with this study. The next step is to use this LCI data as input for a Life Cycle Impact Assessment (LCIA) to identify the environmental impact with the largest relevance for Ghana's timber sector. A comparison and evaluation of existing life cycle methods for this purpose is expected to be finalized and published soon. Results from both LCI and LCIA will be the basis for a detailed improvement assessment as a last step.

Africa is the least known continent in the scientific LCA world, because it has often been a difficult place to do scientific research as a result of limited infrastructure for production inventory data. Good data keeping in the Ghana timber industry will help to build the required research capacity to develop local familiarity and competence in LCA techniques and applying these techniques will help to further certify tropical timber international markets.

Chapter 4: Life Cycle Impact Assessment (LCIA) of the timber sector in Ghana

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Chapter 4: Life Cycle Impact Assessment (LCIA) of the timber sector in Ghana

Abstract

Background, aim and scope: Most LCIA approaches in LCA are developed for western countries. Their LCIA approaches and characterization methodologies for different impact categories may not be necessarily relevant to African environmental conditions, and particularly not for the timber sector in Ghana. This study reviews the relevance of existing impact categories and LCIA approaches, and uses the most relevant for the timber sector of Ghana.

Materials and methods: The study reviewed twenty-three LCIs and LCAs on forestry, timber and wood products for relevant impact categories and LCIA approaches for their relevance to the specific conditions in Ghana. This study uses an earlier LCI study of the timber industry as a starting point for an additional LCIA. We next performed a correlation and regression analysis to learn whether wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss and the other impact categories.

Results and discussion: The literature review shows that no LCI or LCA studies were developed for Africa or the tropics. The LCIA approaches in the reviewed LCAs indeed show to take their basis in the environmental problems in Western countries, and characterization methodologies relating to how these problems manifest themselves in the western world. Characterization methodologies for different impact categories in CML-2000 and other LCIA approaches may not be necessarily relevant to African tropical environmental conditions, and particularly not for the timber sector in Ghana. This situation hampers the reliability of our LCIA and points to a serious research gap in LCIA development in general.

We applied the scientifically well-recognized CML 2000 to the earlier LCI results and characterized the preliminary selected impact categories of global warming, acidification, eutrophication, photochemical oxidant formation, and human toxicity. The correlation analysis indicated that wood waste is indeed strongly correlated with land use as proxy for biodiversity loss, and also positively correlated with the other five impacts results. It can be concluded that wood waste production is a major driving force for biodiversity loss, and a sufficiently good single indicator for all other environmental impact in the timber sector of Ghana.

Conclusion: This study and the previous LCI paper are pioneering a field not yet explored, since the correct impact indicators are not yet developed or adapted to tropical conditions. The development of LCIA approaches in the tropics may be the start of a never ending journey in LCA research in Africa, particularly Ghana.

Keywords: Ghanaian timber sector • environmental impacts • functional units • Life Cycle Impact Assessment (LCIA) • Tropical wood

Introduction

Eshun et al. (2010a) compiled a comprehensive Life Cycle Inventory (LCI) for the timber sector of Ghana. This LCI quantified the use of land, material and energy resources as well as emissions and wastes for five major products (i.e. air dried lumber, kiln dried lumber, plywood, veneer and furniture parts). Their results indicated that land-use change for timber production from 2000 to 2007 in Ghana is 34.0 x 10^3 ha per year. At this rate, Ghana will be completely deforested by 2025. The total energy consumed by the timber sector was estimated at 1.9 x 10^9 MJ per year with a related CO_2 emission of 0.7 million tons per year, dominating overall greenhouse gas emissions of CO_2, CH_4 and N_2O. The timber industry generates 0.8 million m^3 wood waste per year, which constituted 62% of the initial wood input to the timber industry, and contributed enormously to the rapid depletion of the country's timber resources (Eshun et al. 2010a).

The five products in the LCI of Eshun et al. (2010a) were further compared for three different functional units (m^3, kg or €). The usual functional unit of 1 m^3 of product produced was expected to insufficiently express the different services provided by the five products. We therefore selected two additional functional units. One defined as 1 kg of product produced and the other as 1 euro of product produced. The chosen functional unit shows to influence on the inventory results and therewith plays a crucial role in the environmental comparison of production lines in Ghana's timber sector. The money-based functional unit, which also seems most appropriate as a measure for the function of the different timber products considered, favours the value-added products. Value-added products with strict forestry management practice holds a promising future for the sustainability of this sector (Eshun et al. 2010a).

Only the interactions between economic processes and the environment were quantified by Eshun et al. (2010a), but they did not yet estimate environmental impacts. This can be done by a formal LCIA that interprets the earlier LCI results in terms of environmental impacts. Applying an LCIA to LCI results, i.e. performing a complete Life Cycle Assessment (LCA), will help the industry to prioritize areas for environmental action and, at the same time, get the best return on their investments by reducing their operational environmental impact (Berkhout 1995, Daniel and Pappis 2008).

Most LCIA approaches in LCA are developed for western countries. Their specific environmental problems have become the "standard list" of impact categories included in most LCAs. Also the methodologies for characterizing those impacts are based on how these problems manifest themselves in the western world (SETAC 1994, Alsema 2000, Tukker 2000, Brentrup et al. 2004, Pennington et al. 2004). The "standard problem list" and the characterization methodologies for different impact categories may not be necessarily relevant to African environmental conditions, and particularly not for the timber sector in Ghana. An evaluation of the relevance of existing LCIA approaches in LCA for the Ghanaian timber sector is urgently needed.

The objective of this paper is to review the relevance of different existing LCIA approaches, and to identify and apply the most relevant one to the LCI results of Eshun et al. (2010a). We will thus use the most suitable approach to quantify major environmental impacts of the timber sector in Ghana. This study will provide a unique insight into the usefulness of different tools for evaluating environmental policies in Ghana and more generally in most of Africa.

Materials and methods

This study uses the LCI study of Eshun et al. (2010a) as a starting point for an additional LCIA. LCIA is the third phase of an LCA studies. LCIA aims at evaluating the significance of potential environmental impact of the results of inventory analysis (the second phase of an LCA), within the framework of the defined goal and scope of the study (first phase on an LCA) (ISO - 14044 2006).

The LCIA phase consists of mandatory and optional steps. The mandatory steps of the LCIA approach are made up of the following: (1) the selection of impact categories, category indicators and characterization methodology, (2) the assignment of LCI results to the selected impact categories (classification) and (3) the calculation of category indicator results (characterization). The additional optional steps of the LCIA approach consist of the following: (4) normalization, which expresses potential impacts in ways that can be compared, (5) grouping, i.e. sorting and possibly ranking of the impact categories, (6) weighting, i.e. converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices, and (7) data quality analysis i.e. to better understand the reliability of the collection of indicator results and the LCIA profile.

The use of the optional steps depends on the goal and scope of the LCA studies, because they are not allowed in comparative LCAs which results are to be disclosed to the public (ISO - 14044 2006, ILCD 2010). The optional steps, and specifically the weighting step, have been criticized for their subjectivity. Goyal and Deshpande (2001) therefore argued, for example, to increase accuracy by defining clear and exhaustive criteria, based on experts' opinions, to specify the precise weights. We avoid in this study the optional steps and focus only on the mandatory steps in the LCIA phase.

The calculation of category indicators (i.e. mandatory step 3) becomes relevant once impact categories and their characterization methodology have been selected (i.e. mandatory step 1), and individual inventory data are assigned to the selected impact categories (i.e. mandatory step 2). The characterization methodology typically uses characterization factors. Characterization factors represent the potential of a single emission or resource consumption to contribute to a given impact category (ISO - 14044 2006). Results for category indicators or environmental impacts are usually calculated by accumulating the products of the individual inventory data multiplied with its characterization factors (CF) for the given impact category as shown in Equation (1):

$$\text{Impact category indicator} = \sum \text{Inventory data (II)} \bullet \text{CF(II)} \qquad (1)$$

Where (II) stands for an individual inventory item.

From the foregoing description of the LCIA phase, our study on Ghana's timber sector was performed in four steps:

Selection of relevant impact categories

An extensive literature search was carried out that yielded twenty-three life cycle studies on forestry, timber and wood products in four journals (Table 4.0). For each of them, we identified the country where the study was performed, the content of the inventory analysis, whether an LCIA phase was included, and which impact categories then were used (Table 4.0). This overview was used to arrive at the relevant selection of impact categories for extending the LCI of Eshun et al. (2010a) with an LCIA into an LCA of the timber sector in Ghana.

Selection of relevant LCIA approach

This second step evaluated in more detail approaches used in the LCIA phase. This evaluation was to ascertain the optimal relevance of LCIA approach used and the characterization methodology applied to the environmental impact assessment of timber sector in Ghana.

Application of selected LCIA approach to selected impact categories

The LCI results from Eshun et al. (2010a) were then translated into potential environmental impacts with help of Equation 1 for the selected relevant impact categories by using the selected LCIA approaches with its related characterization methodology (compliant with ISO – 14044 (2006). LCIA results were calculated for the whole Ghanaian timber sector, as well as for the three functional units in Eshun et al. ((2010a) ; see introduction).

Correlation analysis between different environmental impact

We performed a correlation and regression analysis to learn whether wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss and the other impact categories as well. This would enormously simplify a follow-up study in which we intend to explore environmental improvement options for economic activities in the timber sector in Ghana.

Results

Selection of relevant impact categories

This section reviews the twenty-three life cycle studies found on forestry, timber and wood products (Table 4.0). Ten studies stopped, similar as Eshun et al. (2010a), at the inventory analysis phase. We call these, in accordance with common ISO-14044 terminology, LCI studies. The other thirteen studies performed an additional LCIA and therewith comply with the definition of an LCA in ISO-14044 (2006).

Most of the LCI studies aimed to quantify energy demands and energy-related emissions. Six out of these ten LCI studies were conducted in the USA and four in Europe. None of the LCI studies specified why an additional LCIA phase was excluded. This could relate to the sceptical attitude of some LCA practitioners towards the LCIA phase. Also the mandatory steps contain in their opinion inherent subjective value judgements (Barnthouse et al. 1997).

Most LCA-practitioners regard LCIA as an essential phase in LCA. An LCI study only quantifies interactions between processes and the environment, but does not assess the subsequent environmental impacts of these interactions. The information from an LCI results therefore does not allow concluding on whether and to what extent a single inventory parameter contributes to the environmental problems. This bears the danger of picking single aspects of the inventory results and draw unsupported conclusions. A subsequent LCIA phase provides additional information about how harmful emissions are to the environment. ISO – 14044 (2006), clearly states that an LCA study without LCIA is not a LCA, but just a LCI study.

Thirteen out of the twenty three life cycle studies included an LCIA phase. Eleven of these LCA studies were conducted in Europe (Table 4.0). Abiotic resources, biotic resources and ecotoxicity impact categories were the least studied categories in these studies. Most studied impact categories were global warming, acidification, eutrophication, photochemical oxidant and human toxicity.

Table 4.0: Overview of twenty-three life cycle studies on forestry, timber and wood products to identified the country where the study was performed, the content of the inventory analysis, whether an LCIA phase was included, and which impact categories used (x)

Product system	Country	Environmental impact category used										Content of the LCI studied
		G W	OD	Ac	Eu	PO	Et	Ht	AR	BR	EU	
Forestry (Michelsen et al 2008)	Norway	x		x	x	x		x				Activity-related emissions
Wood-based heating systems (Solli et al. 2009)	Norway	x		x	x	x		x			x	Energy-demand and related emissions
Wood & other materials (Petersen and Solberg 2005)	Norway/ Sweden	x	x	x	x	x		x			x	Energy-demand and related emissions
Forestry (Lindholm and Berg 2005)	Sweden											CO_2-related emissions
Wood transport (González-García et al. 2009b)	Sweden	x		x	x	x					x	Energy-demand and related emissions
Forestry & pulpwood (González-García et al. 2009a)	Sweden/ Spain	x		x	x	x					x	Energy-demand and related emissions
Wooden containers (Gasol et al. 2008)	Spain	x	x	x	x	x		x	x	x	x	Material & energy-related emissions
Hardboard (González-García et al. 2009c)	Spain	x	x	x	x	x	X	x	x		x	Material & energy-related emissions
Wood wastes (Rivela et al. 2006b)	Spain	x	x	x	x	x	X	x		x	x	Wood waste-related emissions
Particleboard (Rivela et al. 2006a)	Spain											Energy-demand and related emissions
Medium density fibreboard (Rivela et al. 2007)	Spain/ Chile											Energy-demand and related emissions
Wood floor (Nebel et al. 2006)	Germany	x	x	x	x	x					x	Material and energy-related emissions
Wood and packaging materials (Hischier et al. 2005)	Switzerland											Materials & energy-related emissions
Waste wood (Werner et al. 2007)	Europe	x	x	x	x	x	X	x	x	x	x	Energy-demand and related emissions
Wooden products (Werner and Richter 2007)	Europe US Australia	x	x	x	x	x		x			x	Material & energy-related emissions
Wood-fibre-reinforced polypropylene composites (Xu et al. 2008)	Australia	x	x	x	x	x	X				x	Energy-demand and related emissions
Softwood lumber production (Milota et al. 2005)	USA											Energy-demand and related emissions
Forestry (Johnson et al. 2005)	USA											Energy-demand and related emissions
Forestry (Aldentun 2002)	USA											Energy-demand and related emissions
Wood products (Puettmann and Wilson 2005)	USA											CO_2 & energy-related emissions
Wood material (Richter and Sell 1993)	USA											Energy-demand and related emissions
Softwood plywood (Wilson and Sakimoto 2005)	USA											CO_2 & energy-related emissions
Woody biomass (Khoo et al. 2008)	Singapore	x		x		x		x				CO_2-related emissions

(GW = Global Warming, OD = Ozone layer depletion, Ac = Acidification, Eu = Eutrophication, PO = Photochemical Oxidant, Et = Ecotoxicity, HT = Human Toxicity, EU = Energy Use, BR = Biotic Resource depletion Use, AR = Abiotic Resource depletion)

Interestingly, these impact categories coincide with the major Dutch and European environmental problems in the early days of LCA (NEPP 1989). The Dutch manual for LCA, was the first providing detailed guidance on LCA methodology (Guinée et al. 1993a, Guinée et al. 1993b). It defined the framework for all later methodological developments, including for the LCIA phase.

According to Pennington et al. (2004), LCA practitioners often select impact categories based on the scope and goal definition of an LCA studies. Unfortunately, the reviewed LCA studies did not argue why certain impact categories were selected and others not. Moreover, none of the LCA studies discussed biodiversity loss and wood waste, which are major environmental impacts in Ghana's timber sector (Awanyo 2007). Possible reasons for this omission might be that charactering biodiversity loss is at an early developmental phase (Udo de Haes et al. 2002, Dubreuil et al. 2007, Michelsen 2008), whereas waste is often considered as remaining part of the technosphere and then not as an impact category in itself.

The reviewed list of impact categories provides representative information for LCI and LCA studies in the timber sector in general. Table 4.0 shows that no LCA studies were done in Africa or the tropics. There is thus a need to decide on a list of impact categories relevant for our LCA study in Ghana. According to ISO-14044 (2006), the list of selected impact categories has to comply with internationally accepted practice. Based on this and Table 4.0, the following impact categories were preliminary selected: global warming (GW), acidification (AC), eutrophication (Eu), photochemical oxidant formation (PO), and human toxicity (HT). We omitted Ozone Depletion (OD) and Biotic Resource use, but added wood waste (WW) and biodiversity loss (BD) to this list. We limited the impact category Abiotic Resource use (AR) to Energy Use (EU; though this and wood waste are basically inventory items). These categories were taking as starting point to address the major environmental problems of Ghana's timber sector.

Selection of relevant LCIA approach

This section continues with the thirteen LCA studies in Table 4.0 and closer looks into their LCIA phase. Table 4.1 summarizes the overall LCIA approach used and the specific category indicator and characterization factors applied for separate impact categories.

Four LCIA approaches were identified: Environmental Design of Industrial Products- 97 (EDIP-97), CML 2 baseline- 2000 (CML-2000), Eco-indicator 95 and Eco-indicator 99. EDIP-97, CML-2000 and Eco-indicator 95 follow a mid-point approach in LCIA. Mid-point approaches places impact indicators relatively close to environmental interventions and are based on established knowledge. The amount of subjectivity and uncertainty involved in a mid-point approach is therefore considered limited. However, the main disadvantage of this approach is that the results are sometimes hard to interpret across indicators. Additional subjective information is needed to for that. Eco-indicator 99 has an end-point approach to environmental impact assessment. End-point approach places indictors relatively close to the end-points, i.e. safeguarding issues such as human health, ecosystem quality and resources. The end-point approach allows decision makers to easily interpret results, but its main disadvantage is the high level of uncertainty (Guinée et al 2001). For example, Gasol et al. (2008) used CML-2000 approach instead of Eco-indicator 99 to avoid subjectivity of impact results. This study will use a mid-point approach since its effects can be calculated with more certainty than the end-point approach. As knowledge develops, the mid-point effects will move closer to the end of the cause-effect chain.

Three LCIA approaches (EDIP-97, CML-2000 and Eco-indicator 95) cover several impact categories for which characterization results are expressed in the same units. The documentation for those three approaches reveals that they basically use the same characterization methodology for global warming, ozone layer depletion, acidification, eutrophication and photochemical oxidant. Characterization methodology for these impact categories follows a mid-point approach. All four LCIA approaches differ for impact categories such as ecotoxicity and human toxicity (Table 4.1). That is visible from the category indicators for ecotoxicity and human toxicity using different units across the different approaches. However, all modelled use a similar key-property approach in which the most important fate characteristics are included in a simple modular framework. This has the advantage that relatively few substance data for calculation of the characterization factors are required.

Some LCA studies from Table 4.1 combined characterization methodology in the followed LCIA approach with characterization methodology from other studies. That specifically applies to human toxicity where this combination of characterization methodologies enabled the study to determine toxicological impact results for substances covered in the additional characterization methodology used. Werner and Richter (2007), for example, combined CML-2000 and Eco-indicator 95, because CML-2000 does not include characterization factors for chemical components used in preserving materials in an adequate manner. Solli et al. (2009) in his LCA of wood-based heating systems in Norway employed CML- 2000 approach for most selected impact categories. However, the characterization methodology for human toxicity combined Johansson et al. (2004) and Hertwich et al. (2006).

The land use impact category was only covered by Eco-indicator 99 (Table 4.1). The other three LCIA approaches did not cover land use as an impact category. Land use is nowadays considered an inventory item contributing to the impact category biodiversity loss. There is no consensus yet on how to define its category indicator, i.e. how to characterize it (Udo de Haes et al. 2002, Michelsen 2008). Solid waste impact category was only covered by EDIP-97 and Eco-indicator 95 (Table 4.1). CML-2000 and Eco-indictor 99 do not cover solid waste as a separate impact category. This is because solid waste is in these approaches considered as a by-products entering a waste-treatment process or being recycled and therefore belonging to the technosphere (Klöpffer 2009).

EDIP-97, Eco-indicator 95 and Eco-indictor 99 approaches refrain from spatial differentiation (Table 4.1). This implies that the studies did not consider the geographic variability of the impact assessed. The use of site generic characterization factors is only appropriate to evaluate environmental impacts for which the location of its perpetrator is unrelated. The assessment's relevance of other environmental impacts may be affected by using site generic characterization methods because its occurrence is related to the location of the perpetrator. The use of a characterization methodology without spatial differentiation could lead to invalid results. The inclusion of geographical information in LCIA will increase the accordance between the impact predicted by LCA studies and the expected occurrence of actual impact (Potting and Hauschild 1997). Potting et al. (1998) were the first to develop and calculate sophisticated characterization factors that establish the relation between the region of emission and its environmental impacts.

Recent LCIA approaches as EDIP2003 (Hauschild and Potting 2005) and CML-2000 (Guinée 2002) now include site-dependent characterization factors. Available sets of site-dependent factors unfortunately only cover Europe and North America (Potting and Hauschild 2006). Clearly, there is a need to elaborate practical models for the inclusion of spatial differentiation into LCIA for other continents, including Africa. Future research should focus on developing LCIAs geographically specific to continents, regional concerns and situation dependent to better reflect local variations for such impacts that are not global in nature. For the time being, Hauschild and Potting (2005) recommend to use site-generic characterization factors for regions and continent not covered by site-dependent characterization factors.

Table 4.1 Evaluation of LCIA methods and characterization factors in LCA studies in the timber sector in Table 4.0.

Impact category	EDIP – 97 (Wenzel et al. 1997)	CML baseline- 2000 (Guinée et al. 2000)	Eco-indicator-95 (Goedkoop 1995)	Eco-indicator-99 (Goedkoop and Spriensma 2000)
References of LCA studies using the various LCIA methodoloy	(Khoo et al. 2008)	(Petersen and Solberg 2005, Nebel et al. 2006, Werner et al. 2007, Werner and Richter 2007, Gasol et al. 2008, Michelsen et al 2008, González-García et al. 2009a, González-García et al. 2009c, Solli et al. 2009)	(Werner and Richter 2007)	(Rivela et al. 2006b, Xu et al. 2008, González-García et al. 2009b)
Global warming	kg CO_2 eq	kg CO_2 eq	kgCO_2 eq	DALY *
Ozone layer depletion	kg CFC 11 eq	kg CFC 11eq	kg CFC 11 eq	DALY *
Acidification	kg SO_2 eq	kg SO_2 eq	kg SO_2 eq	PAF m^2yr *
	mole of H^+ eq			
Eutrophication	kg NO_3 eq	kg PO_4 eq	kg PO_4 eq	PAF m^2yr *
Photochemical oxidant	kg C_2H_4 eq	kg C_2H_2 eq	kg C_2H_4 eq	kg C_2H_4 eq
Ecotoxicity	m^3 in water	kg 1,4 DB eq	PAF*m^2yr	PAF m^2yr *
Human toxicity	m^3 in air	kg 1,4 DB eq		
Carcinogens			kg B (a) P	DALY *
Respiratory organics/inorganics			DALY *	DALY *
Land use				PDF m^2yr *
Solid waste	kg		kg	
Abiotic resources depletion		kg Sb eq		
Energy Resources			MJ LHV *	MJ Surplus

* DALY= Disability Adjusted Life Years, PDF = Potentially Disappeared Fraction, PAF=Potentially Affected Fraction, LHV = Lower Heat Value

Note: Gasol et al (2008) combined CML-2000 and Cumulative Energy Demand (CED) methods, Werner et al (2007) combined Eco-indicator 95 and CED methods and Solli et al (2009) combined CML-2000 and characterization factors of (Johansson et al. 2004, Hertwich et al. 2006)

Our review of LCIA approaches and characterization methods shows that CML-2000 is the most frequently used and also the most internationally accepted and recognized impact approach in LCAs of timber products. CML-2000 uses mid-point indicators that are relatively transparent in the underlying physical modeling. This study will therefore as a starting-point follow the CML-2000 approach for our environmental impact assessment of the timber sector in Ghana, but seeks to combine it with other approaches where relevant.

Application of the relevant LCIA approach for LCA studies in the timber sector

This section applies CML 2000 to the LCI results of Eshun et al. (2010a) for characterization of the impact categories of global warming, acidification, eutrophication, photochemical oxidant formation, and human toxicity. Table 4.2 provides the CML-2000 characterization factors used for each of these impact categories. Deviating from the recommendation of Hauschild and Potting (2005), we used the conventional characterization factors for acidification, i.e. alternative generic acidification potentials in Guinée (2002). This is because the site-generic factors in the baseline-approach are based on European data and considered not to adequately reflect the African situation. We therefore decided to use the conventional or alternative factors that quantify the maximum acidifying potential of the substances considered. Wood waste, which basically is an inventory items, is characterized by simply adding together the contributions to them. Characterization of biodiversity for the timber sector of Ghana is addressed at the end of this section.

Figure 4.0 presents the overall LCIA results for each of the three functional units. The results for each impact category show, obviously in accordance with Eshun et al. (2010a), their sensitivity for the choice of functional unit. This indicates any policy choice for each impact category must consider a correct choice of functional units.

Figure 4.1 presents the overall LCIA results for the total timber sector in Ghana. These results are below discussed per impact category separately.

The total global warming impact from CO_2, CH_4 and N_2O emissions amounted to approximately 765 kt CO_2–equivalents per year (Table 4.3). Air dried lumber contribute little (only 1%) because its reliance on natural air for drying. Kiln-dried lumber, plywood, and veneer production lines were then the main contributors with a score of 30% each (Table 4.3). The over-dependence on wood waste for drying wood product in the timber sector thus threatens the sustainability of Ghana's natural forest.

The total annual acidifying impact from SO_2 and NO_X amounted to 1,179 t SO_2 – equivalent per year (Table 4.3). When the contributor of total acidifying impacts was considered, we found that kiln dried lumber production contributed the largest proportion (i.e. 33%). This high value is as a result of the intensity of the drying processes. Plywood production was second with 28%, while furniture contributed only 12% (Figure 4.0) because of its lower fuel usage.

The total eutrophying impact amounted to 169 t PO_4 –equivalent per year (Table 4.3). Kiln dried lumber was the largest contributor with a share of 35%. This is the result of the intensity of the kiln drying processes. The least contributor is furniture production with a share of 11%. This low eutrophying impact relates to the many manual activities at its final production stage.

Table 4.2: Selected impact categories, LCIA method and characterization factors applied to the timber sector of Ghana.

Impact Category	Scale	Examples of LCI Data (i.e. classification)	Characterization Factor	Description of Characterization Factor	Reference
Global Warming	Global	Carbon Dioxide (CO_2) Methane (CH_4) Nitrous Oxide (N_2O)	1kg = 1 CO_2 eq 1kg = 21 CO_2 eq 1kg = 310 CO_2 eq	Converts LCI data to carbon dioxide (CO_2) equivalents Note: global warming potentials for 100 year potentials.	(Houghton et al. 1996)
Acidification	Regional	Sulfur Dioxide (SO_2) Nitrogen Oxides (NOx)	1kg = 1 SO_2 eq 1kg = 0.7SO_2 eq	Converts LCI data to SO_2 equivalents.	Heijungs et al (1992)
Eutrophication	Regional Local	Nitrogen Oxides (NOx)	1 kg = 1.3 PO_4 eq	Converts LCI data to PO_4 equivalents	Heijungs et al (1992)
Photochemical Smog	Local	Non-methane hydrocarbon (NMVOC) Carbon mono - oxide (CO) Methane (CH_4) Nitrogen Oxides (NOx)	1kg = 0.416 C_2H_2 eq 1kg = 0.027 C_2H_2 eq 1kg = 0.006 C_2H_2 eq 1kg = 0.028 C_2H_2 eq	Converts LCI data to ethylene equivalents.	(Guinée et al. 2000)
Human toxicity	Local	Sulfur Dioxide (SO2) Nitrogen Oxides (NOx)	1kg = 0.096 $C_6H_4C_{i2}$ eq 1kg =1.2 $C_6H_4C_{i2}$ eq	Converts LCI data to dichlorobenzene ($C_6H_4C_{i2}$) equivalents	CML (2002)
Wood waste	Local	Quantity of wood waste generated	kg of wood waste produced	Converts LCI data to the quantity of wood wastes output	(Udo de Haes et al. 1999)

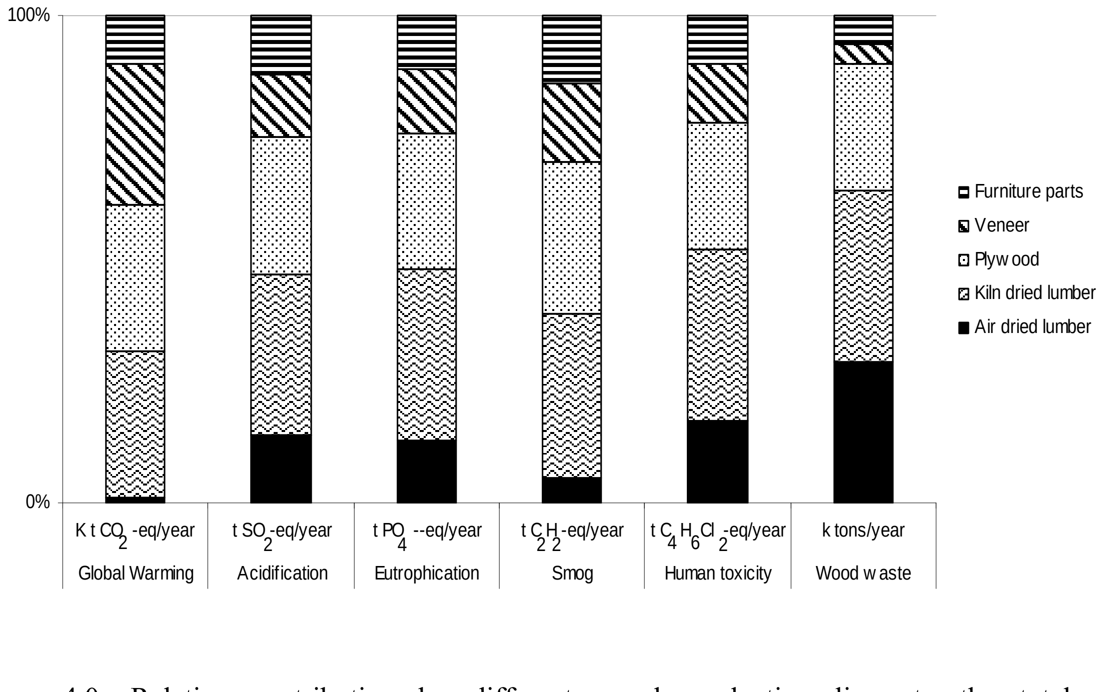

Figure 4.0: Relative contribution by different wood production lines to the total environmental impact of the timber sector of Ghana

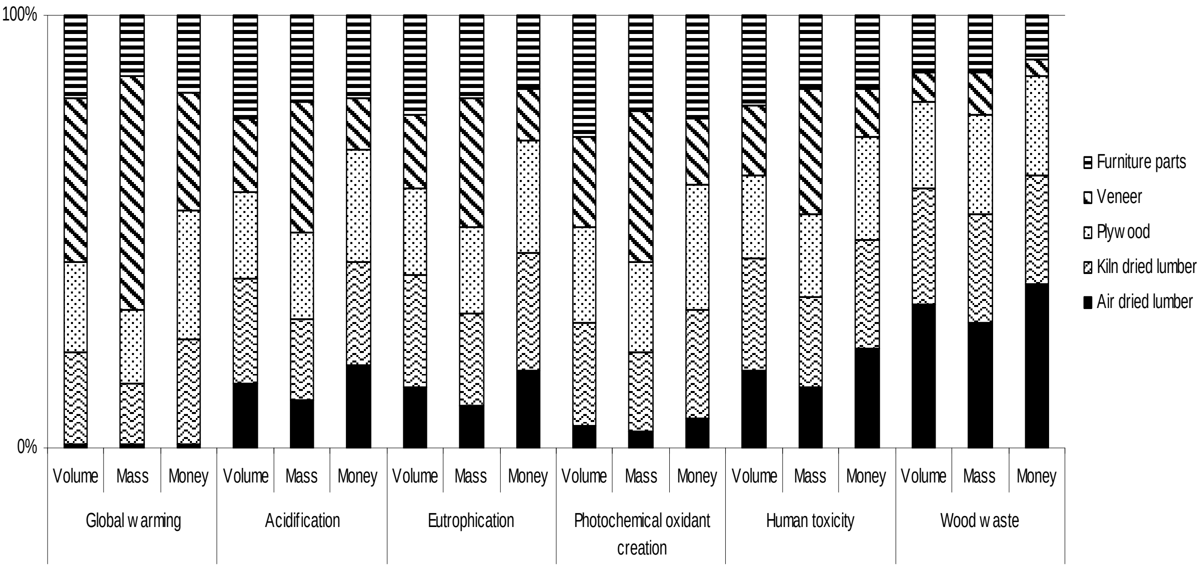

Figure 4.1: Influence of functional unit on environmental impact results for 5 major production lines in Ghana's timber sector to Volume (m^3), mass (kg) and money (€)

The total impact of tropospheric ozone precursor compounds in the timber sector of Ghana amounted to about 1kt ethylene–equivalent per year (Table 4.3). Kiln dried lumber production had the highest tropospheric ozone precursor's impact with a share of 34%. The second highest tropospheric ozone precursor's impact was plywood production with a share of 31%. Air dried lumber production was the least contributor (c.f. Figure 4.0).

The total impacts of human toxicity compounds in the Ghanaian timber sector amounted to about 58 t $C_6H_4Cl_2$-equivalent per year (Table 4.3). Kiln dried lumber contributed the highest impact with a share of 35%. The second contributor to human toxicity impact was plywood production with a share of 26% (Figure 4.0).

The total wood wastes of the timber industry, as already quantified in Eshun et al. (2010a), amount to 288 kt per year (Table 4.3). This value does not include the amount generated at the forestry subsystem because of lack of appropriate data. The contributions to wood waste by the various production lines are illustrated in Figure 4.0. Kiln dried lumber contributed to the highest production of wood waste with a share of 35%. Veneer product is the least contributor to wood waste in the timber industry in Ghana with a share of 4%.

A comprehensive LCA is supposed to include all relevant environmental concerns. For the timber sector biodiversity is a major concern because of the land degradation by deforestation and desertification. Unfortunately biodiversity is one of the least mature impact categories in LCA approaches. There have been several attempts to develop biodiversity impact indicators based on biodiversity concepts such as species richness (Weidema and Lindeijer 2001), ecosystem dynamics (Wagendrorp et al. 2006), threats to species (Müller-Wenk et al. 2002) and habitat protection(Schenck 2001). All these indicators exhibit space-dependent and non-linear behavior, reflecting the spatial patterns of biodiversity. Developing biodiversity-loss indicators for LCA is still in its early stage (Lindeijer et al. 2002). We therefore decided to stick for this impact category to land use as quantified by Eshun et al. (2010a). Eshun et al. (2010a) quantified land use, which is basically an inventory item and not an impact category, as the area of tropical forest harvested.

Table 4.3: Overview of the total environmental impact contributions from the five production lines of the timber sector in Ghana

Impact Category	Emissions	Products Air dried lumber	Kiln dried lumber	Plywood	Veneer	Furniture parts	Total
Global warming	CO_2	8	219	223	219	77	745
($ktCO_2$ -eq/year)	CH_4	0	6	3	2	1	12
	N_20	0	3	2	2	1	8
Total		**8**	**228**	**229**	**222**	**78**	**765**
%		1	30	30	29	10	100
Acidification (t SO_2 -eq/year)	SO_2	53	76	50	18	25	222
	NO_X	117	320	278	130	112	957
Total		**170**	**396**	**328**	**148**	**137**	**1,179**
%		14	33	28	13	12	100
Eutrophication (t PO_4 -eq/year)	NO_X	21	58	47	22	19	169
Total		**21**	**58**	**47**	**22**	**19**	**169**
%		13	35	28	13	11	100
Photochemical	NMVOC	53	119	72	35	62	305
oxidation formation	CO	0	238	247	130	84	699
(tC_2H_2-eq/year)	CH_4	0	2	1	0	0	3
	NO_X	5	13	10	5	4	37
Total		**58**	**372**	**330**	**170**	**150**	**1,080**
%		5	34	31	16	14	100
Human toxicity ($tC_6H_4Cl_2$-eq/year)	SO_2	5	7	5	2	2	21
	NO_X	5	13	10	5	4	37
Total		**10**	**20**	**15**	**7**	**6**	**58**
%		17	35	26	12	10	100
Wood waste (kt/year)		82	101	76	10	19	288
%		29	35	26	4	6	100

Correlation analysis between different environmental impacts

The LCIA phase was initially introduced in LCA to facilitate interpretation of its results by reducing the large number of inventory items to a limited number of impact categories (Potting et al. 1998). Eshun et al. (2010a) quantified 9 inventory items, whereas our LCIA here covers 7 impact categories. Our LCIA thus hardly facilitates interpretation by its number of impact categories that is roughly similar to the number of inventory items in Eshun et al. (2010a).

The importance of LCIA gradually moved to enhancing the environmental relevance of LCA as a tool when characterization methodology evolved. The above LCIA results quantify the environmental impact of the timber sector activities to the environment. This LCIA results give insight on how harmful the timber sector activities affect the environment as compared to Eshun et al. (2010a) which just quantify only interactions between processes and the environment.

From the results, the enormous amounts of wood waste are a direct result of an inefficient use of the forest resources, and therewith form a major driver of biodiversity loss in the Ghana timber sector. In other words, we consider the amount of waste wood in the timber sector of Ghana to adequately reflect biodiversity loss in Ghana. The other impact categories in our LCIA are more indirectly related to wood wastes. We therefore performed a simple correlation and regression analysis to learn whether wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss, and the other impact categories as well. This would enormously simplify a follow-up study in which we intend to explore environmental improvement options for economic activities in the timber sector in Ghana.

The correlation analysis was performed by statistically verifying the correlation between wood wastes land use and the other five selected environmental impact results. The contributions of each of the five production lines to wood wastes were correlated with their contributions to each of the other impact categories to see if some relationship exists. The variance and the coefficient of determination R^2 values were then calculated. This was to enable the researcher to understand the major contributor to the number of environmental problems in the timber sector of Ghana and to further carry out future improvement research if any.

Figure 4.2 presents the results of the correlation analysis. The results indicated that wood waste correlated positive between land use and the other five impacts results. The correlation between wood waste and land use were the strongest correlation with R^2 value of 0.9. It can be concluded that wood waste production is major driving force for biodiversity loss, and a sufficiently good single indicator for all other environmental impact in the timber sector of Ghana. This correlation will be very useful for preliminary screening of environmental impacts, waste minimization analysis or an evaluation of emerging technologies at early stages of decision making in the timber sector of Ghana.

Discussion

Our LCIA for the timber sector in Ghana uses CML-2000 for the larger part of the selected impact categories. The impact categories in CML-2000 take their basis in the environmental problems in Western countries, Also the CML-2000 methodologies for characterizing those impacts are based on how these problems manifest themselves in the western world (SETAC 1994, Alsema 2000, Tukker 2000, Brentrup et al. 2004(Pennington et al. 2004). Particularly the characterization methodologies for different impact categories in CML-2000 (and other LCIA approaches in Section 4.3.2) may not be necessarily relevant to African tropical environmental conditions, and particularly not for the timber sector in Ghana. This situation hampers the reliability of our LCIA and points to a serious research gap in LCIA development in general.

The integrated coverage of a broad range of impact categories in LCA studies is very important for in particular African tropical countries for several reasons. We consider the preliminary selection of impact categories in Section 4.3.2 as relevant for the African continent (but not exhaustive).

Firstly, Africa is a developing continent and its quest to catch up with the developed economies is likely to add up to an increasing energy use and related greenhouse gas emissions (IPCC 2007b). This development will enhance climate change. Climate change will leads to more increase forest fires, biodiversity loss, increased adverse health impacts from heat-related mortality, pollution, and shifts in infectious diseases. Africa is likely to be hardest hit by the global warming impact because of its vulnerability and adaptive capacity (IPCC 2007b).

Secondly, the timber sector in Africa, particularly Ghana, generates acidifying and eutrophying emissions through activities such as timber harvesting, transportation and production processes. These emissions may be detrimental to human and aquatic life, since most people in Africa have limited access to portable drinking water and depend heavenly on untreated river water. Moreover Africa, particularly, Ghana's current developmental agenda is likely to contribute to acidification, eutrophication and photo chemical oxidation problems in the future.

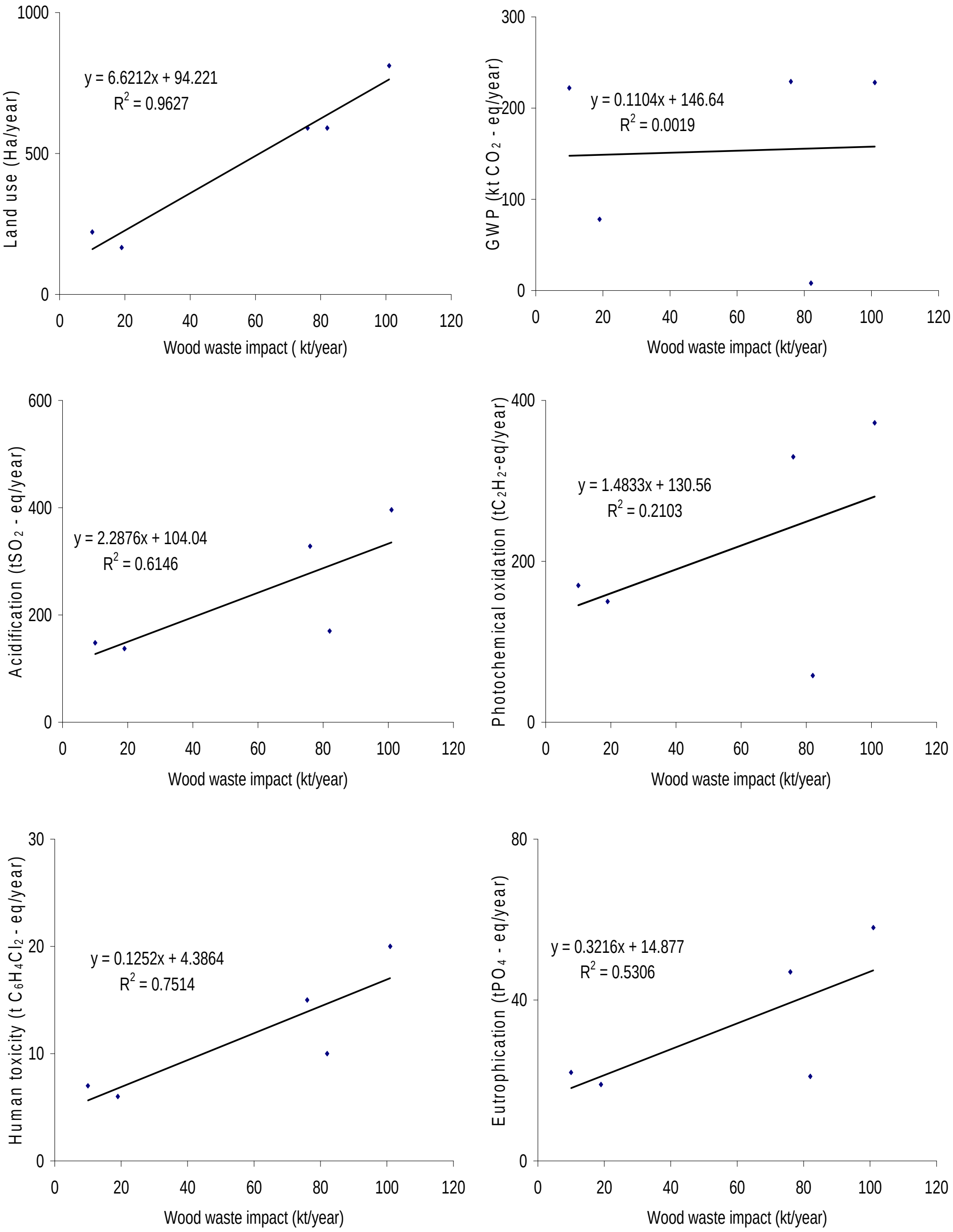

Figure 4.2: Correlation analysis between the contributions of each of the five production lines to wood waste impact and land use as proxy for biodiversity loss and the other five environmental impacts such as global warming, acidification, eutrophication, photochemical oxidation formation, and human toxicity in the timber sector of Ghana

Thirdly, Africa has the highest deforestation and biodiversity loss rate of the world's regions (FAO 2005b). Ghana loses an estimated 340 km^2 of its forests annually (Eshun et al. 2010a). According to Millennium Ecosystem Assessment (2005) and IPCC (2007a) future climate change is likely to have significant repercussion for biodiversity through existing threats like tropical deforestation and unstained timber harvesting. According to Dionco-Adetayo (2001), for 1 m^3 of tree harvested in a tropical forest about 0.8% goes to waste. In Ghana's tropical rain forest, wood waste is one of the most abundant, cost-effective, and environmentally friendly biomass resource but this waste is either left in forests (for firewood) or landfills, or sent to boilers to generate heat and steam for drying wood products. This leads to air pollutants and other environmental problems. The environmental, economic and social considerations for adding value to wood waste far outweigh the use of wood waste as firewood or fuel in drying wood (Rivela et al. 2006a). In order to sustainably manage Ghana's timber sector wood waste problems have to be addressed. In LCA, wood waste is generally not addressed as an impact category.

Fourthly, Land degradation is also serious issue in Africa (UNEP 2002). Erosion as a result of sand and gravel mining, excessive farming and mining in forest reserves are common land degradation problems in Africa (UNEP 2007). Addressing the issue of land degradation through the use of LCA in Africa is a vital key to help Africa reduce poverty, and achieve some of its targets as set out under the Millennium Development Goals.

Our review of LCIA approaches and characterization methods confirms that most LCIA in LCA take their basis in the environmental problems in western countries, and their characterization methodologies relating to how these problems manifest themselves in the western world. Available sets of site-dependent factors unfortunately only cover Europe and North America (Potting and Hauschild 2006). The characterization methodologies for different impact categories may not be necessarily relevant to African environmental conditions, and particularly not for the timber sector in Ghana. This review shows that, there is a need to elaborate practical models for the inclusion of spatial differentiation into LCIA for other continents, including Africa. According to the evaluation of LCIA approaches and Characterization methods, CML-2000 is the most frequently used and also the most internationally accepted and recognized impact approach in LCAs of timber products. CML-2000 uses mid-point indicators that are relatively transparent in the underlying physical modeling. This study therefore as a starting-point applies CML 2000 to the LCI results of Eshun et al. (2010a) for characterization of the impact categories of global warming, acidification, eutrophication, photochemical oxidant formation, and human toxicity. We also performed a correlation and regression analysis to learn whether wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss and the other five selected impact categories. The correlation analysis indicated that wood waste is indeed strongly correlated with land use as proxy for biodiversity loss, and also positively correlated with the other five impacts results. It can be concluded that wood waste production is major driving force for biodiversity loss, and a sufficiently good single indicator for all other environmental impact in the timber sector of Ghana. This correlation will be very useful for preliminary screening of environmental impacts, waste minimization analysis or an evaluation of emerging technologies at early stages of decision making in the timber sector of Ghana.

Finally, it is therefore critical that this study and the previous LCI paper, Eshun et al. (2010a) are pioneering a field not yet explored, since the correct impact indicators are not yet developed or adapted to tropical conditions. The development of life cycle impact assessment approaches in the tropics may be the start of a never ending journey in LCA research in Africa.

When a proper LCIA approach is available for Africa, the improved quality of LCA results may better serve as an investment baseline for understanding industrial and individual company changes. It will also serves as a comparison tool for industry improvement and a benchmark against competing products and materials. In addition, it will provide tools for the corrugated industry to use in performing consistent calculations irrespective of the country. Sustainability and LCIA approaches are strategic bridges to prioritizing and implementing sustainable initiatives projects that will create value for key stakeholders in the timber sector of Africa, particularly Ghana.

Conclusions

Most Life Cycle Impact Assessment (LCIA) approaches are developed for western countries. We reviewed their relevance for the timber sector in Ghana, and applied the most relevant on to the results of an earlier Life Cycle Inventory (LCI) from (Eshun et al. 2010a). Our study now provides preliminary LCIA results and primary data unique for tropical LCA research in Africa, particularly Ghana.

The LCIA results quantified global warming, acidification, eutrophication, photochemical oxidant formation, and human toxicity impacts from timber sector activities. From the study, the enormous amounts of wood waste generated are a direct result of an inefficient use of the forest resources, and therewith form a major driver of biodiversity loss in the Ghana timber sector. In other words, we consider the amount of waste wood in the timber sector of Ghana to adequately reflect biodiversity loss in Ghana.

The other impact categories in our LCIA are more indirectly related to wood wastes. We performed a simple correlation and regression analysis to learn whether wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss and the other five selected impact categories. The correlation analysis indicated that wood waste is indeed strongly correlated with land use as proxy for biodiversity loss, and also positively correlated with the other five impacts results. It can be concluded that wood waste production is major driving force for biodiversity loss, and a sufficiently good single indicator for all other environmental impact in the timber sector of Ghana. This correlation will be very useful for preliminary screening of environmental impacts, waste minimization analysis or an evaluation of emerging technologies at early stages of decision making in the timber sector of Ghana.

The generic approach that was used in this study helped improve the basis for decision-making in the timber sector of Ghana and clearly showed that LCA is a powerful tool for the assessment of environmental impacts of the timber sector in developing countries. However, there is an urgent need to include spatial differentiation into the LCIAs for developing continents, like Africa. Relevant impact categories, LCIA approaches and characterization methods to achieve this have to be further developed to address regional concerns and situations and to better reflect local variations. If used, we can then make a strong contribution to sustainability goals in Ghana and Africa.

Chapter 5: Wood waste minimization in the timber sector of Ghana

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Chapter 5: Wood waste minimization in the timber sector of Ghana

Abstract

This paper explores the potential of minimizing wood waste to reduce the environmental impact in the timber sector i.e. forestry and timber industry subsystem of Ghana. This study is a follow up of 3 earlier studies on the timber sector. These studies consistently identified minimizing wood waste as a major point of departure for reducing the environmental impact of the timber sector of Ghana. When wood waste generated by the 5 wood products were further compared for 3 different functional units (m^3, kg or €). The chosen functional unit were sensitive to the wood waste impact results. The results of our study show that combining technological changes, good operational practices and recycling measures could reduce wood waste by approximately 50%. We therefore conclude that the reduction of wood waste in the timber sector may also reduce the other environmental impacts in the timber sector. Since our earlier studies established that wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss and the other impact categories.

Keywords: Ghanaian timber sector • Tropical wood • Wood waste minimization • Reduction of environmental impact

Introduction

The FAO predicts that global consumption of industrial wood products will increase by 45% in 2020, and experts are concerned about the additional pressure this will put on the world’s forests (FAO 2001). This additional pressure on the world’s forest calls for sustainability of production systems. Sustainable development is a key issue for governments, industries and society, particularly in the timber sector (Labuschagne et al. 2005, Daian and Ozarska 2009, Hallstedt et al.).

For the timber sector, preventing wood waste by improving the efficiency of primary wood utilization could help to reduce environmental impact and also to meet the increasing demand for wood without further impacting the world’s forests (Magin 2001). Wood waste recovery provides in addition a high volume of secondary resource for recycling into new advanced materials. This further enhances the environmental profile of wood. Reducing, recovering and enhancing the utilization of wood waste from harvesting and processing of wood are recognized as one of the top strategic objectives and research areas in Africa.

The Ghanaian timber sector, i.e. forestry and timber industry, plays an important role in the Ghanaian economy by directly contributing with about 6 % to Gross Domestic Product (GDP), and about 11% to total export earnings (Acquah and White 1998, Agyarko 2001). Also the timber sector in Ghana currently faces as one of its major challenges how to reduce the generation of the enormous amount of wood waste along its production life cycle.

According to Dionco-Adetayo (2001), about 0.8 m^3 of every 1 m^3 of tree cut and removed from the forest, goes to waste. These wastes are in the form of damaged residuals (50%), abandoned logs (3.75%), tops and branches (33.75%), stumps (10%), and butt trimmings (2.5%). According to Eshun et al. (2010a), the amount of wood waste generated in the Ghanaian timber industry subsystem, accounted to 0.8 million m^3 per year, which constituted 62% of the initial wood input to the timber industry. This enormous amount of wood waste is used either in steam production boiler for drying wood products or dumped on site. Wood wastage contributes to environmental impacts and also leads to the rapid depletion of the country's timber resources which constitutes a major setback to the sustainable management of timber sector. In a follow-up study, Eshun et al. (2011) identified wood waste as a major driving force to most of the environmental impact in the timber sector of Ghana.

From the forgoing, minimizing wood waste in the entire timber production processes is critical to reduce the concomitant environmental impacts such as global warming, acidification, eutrophication, smog, and human toxicity. Therefore, the objective of this study is to explore the potential for minimizing wood waste to reduce the environment impact in the timber sector of Ghana.

The study will provide managers and operators in the timber sector of Africa, specifically in Ghana, with an enhanced insight into ways to improve productivity, reduce wood waste and sustain the timber sector.

Means and methods

This study is a follow up of three earlier studies on the timber sector of Ghana from (Eshun et al. 2010a, 2010b, 2011). These studies identified minimizing wood waste as a major point of departure for reducing the environmental impact of the timber sector of Ghana. Wood waste in this study is considered as wood that presently has no longer any value at its current location. Wood-waste includes, amongst others, saw dust, shavings, milling residue, cutoffs, trees, branches and bark. It is important to establish a deeper understanding of product life cycles, i.e. from their raw material to the final products, to help set up an analysis of the potential for waste minimization for reducing the environmental impact of the timber sector.

Similar as Eshun et al. (2010a, 2010b), we therefore first divide the timber sector into two subsystems i.e. the forestry subsystem and the industry subsystem. Next we further break down the industry subsystem in its 5 main production lines, resulting in product outputs (Figure 5.0). The five main products outputs were further compared for three different functional units (m^3, kg or €). Also, the usual functional unit of 1 m^3 of product produced was expected to insufficiently express the different services provided by the five products. We therefore selected two additional functional units. One defined as 1 kg of product produced and the other as 1 euro of product produced.

This study uses the data from Eshun et al. (2010a) as a starting point for quantifying the wood waste of the timber sector in Ghana. Eshun et al. (2010a) quantified wood waste in the industry subsystem, but not from the forestry subsystem. Additional information about wood waste from forestry, and about the state of equipment/machinery and potential for wood waste reduction in the whole timber sector was established through interviews with experts, actual plant observations and reviewing of literature. This information was used for the identification of the sources and types of wood waste, and possible minimization measures. In that way, the adopted approach facilitated the optimization of the entire timber production process.

The foregoing description of our system boundary and the data collection process was the basis for our study on wood waste minimization in Ghana's timber sector that was performed in 3 steps:

Identification and quantification of wood waste

The formulation of wood waste minimization strategies in the timber sector requires the identification and quantification, and a causative analysis of all sources of wood waste in the timber sector. This was done for the 5 main wood products of the Ghanaian timber sector for which Figure 5.0 shows the flow diagram of the inputs and consequent outputs from their production lines.

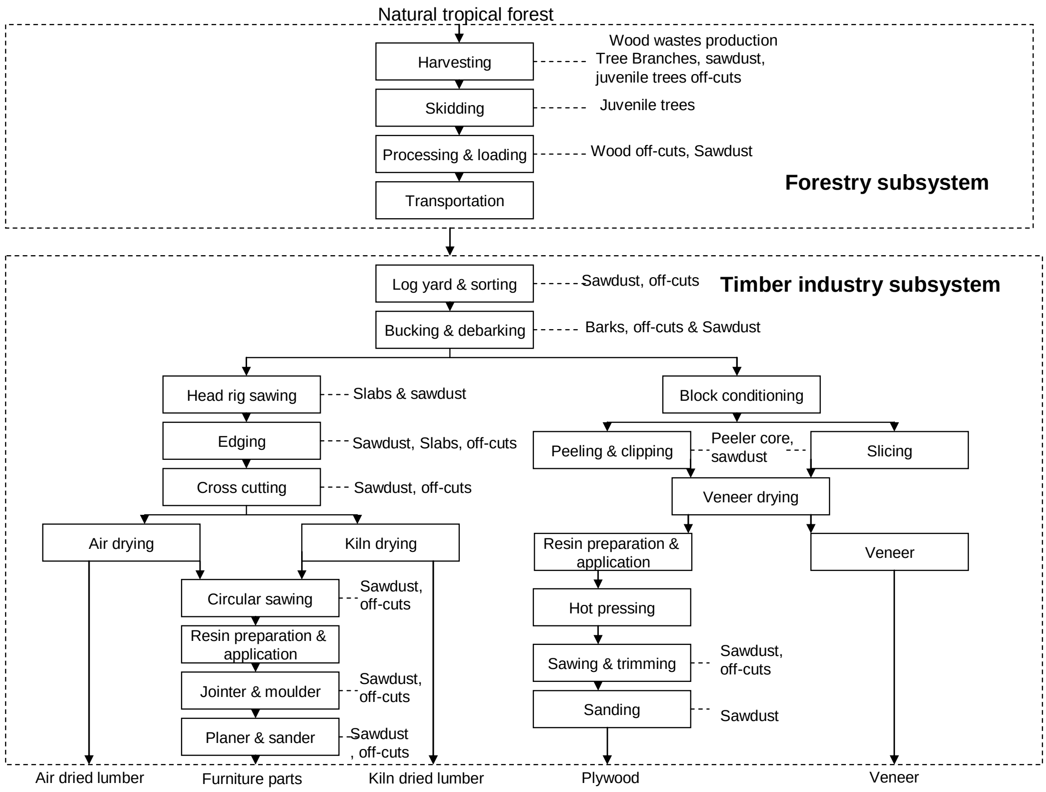

Figure 5.0: Flow chart of the activities and waste production in the formal timber sector in Ghana

Identification of relevant wood waste minimization measures

Identification of waste minimization measures relevant for Ghana was necessary. This involved an inventory of minimization measures and an evaluation of their technical feasibility, economic viability, sustainability and ease of implementation in the Ghanaian timber sector. The resulting overview in combination with the results of Step 1 provides a platform for quantitatively evaluating effective wood waste minimization strategies to reduce the environmental impact in the timber sector of Ghana.

Scenario analysis

This section combined the information from Step 1 and 2 for proposing and analyzing scenarios for the wood waste minimization in the timber sector of Ghana. Scenario analysis is a proven tool that helps in making a strategic planning for the future by testing how decisions made today could affect a company or economy in the future (Saritas and Aylen 2010). The scenarios here are designed to explore the wood waste minimization potential of combined measures to reduce the environmental impacts in the timber sector.

Results

Identification and quantification of wood waste

Table 5.0 presents the results of the quantification of wood waste sources. The quantitative results for the industry subsystem haven been taken from an earlier studies of the timber industry by Eshun et al. (2010a). They quantified the wood waste generation in the timber industry subsystem as 0.8 million m^3 per year. One unique aspect of this study is its quantification of the wood waste in the forestry subsystem. According to Dionco-Adetayo (2001), about 0.8 m^3 of every 1 m^3 of tree cut and removed from the tropical forest goes to waste. The total forest wood waste in Ghana was estimated from combining this assumption with the quantitative results for the industry subsystem from Eshun et al. (2010a). The amount of forest wood waste was calculated to 5.12 million m^3 per year as shown in Table 5.0. All this forest wood waste is left in the forest and never used effectively. This estimation then brings the total wood waste generated in both the forestry and timber industry subsystems to approximately 6 million m^3 per year.

Table 5.0 also shows the contributions of wood waste by the various production lines. Kiln dried lumber contributed to the highest production of wood waste with a share of 34%. Furniture part is the least contributor to wood waste in the timber industry in Ghana with a share of 8%. The wood waste generated by the 5 wood products were further compared for 3 different functional units (m^3, kg or €). The chosen functional unit were sensitive to the wood waste impact results (Figure 5.1).

Tables 5.1 – 5.5 present the results of the identification of wood waste sources and their causative analysis in the timber sector of Ghana. This study identified 19 wood waste sources together with their possible causes, i.e. 3 in the forestry subsystem and 16 in the timber industry subsystem.

The causative analysis was carried out together with experts in the timber sector of Ghana. Tables 5.1 - 5.5 specify for each step in the timber production process, the equipment type presently used, the wood waste type generated, the results of the causative analysis and an estimation of the loss of wood waste as percentage of the wood input per activity in the timber sector. The causative analysis of wood waste was to help in the identification of waste minimization measures. According to Tables 5.1 – 5.5, the causative analysis of wood waste in the timber sector was broadly categorized as technology-oriented and process execution and management-oriented.

The technological-based factors relate amongst others to the type of equipment used, equipment sizes, and equipment efficiency that influence the quantity of wood waste generation. The industry's machinery installations, i.e. equipment, were seen to be obsolete and inefficient and therefore consume more wood than can actually be sustainably provided by the natural tropical forests. Wood conversion inefficiencies of round wood to sawn lumber or other final products were also seen to contribute to the causes of wood waste impact.

Process execution and management factors relate to procedural, administrative, resource management and institutional maintenance practices. These factors were also seen to be some important causes of wood waste generation in the timber sector. To effectively minimize wood waste to reduce the environmental impact in the timber sector of Ghana, there is a need to review literatures and identify the relevant waste minimization measures.

Table 5.0 Estimation of total wood waste production per year of the timber sector in Ghana from Eshun et al. (2010a).

	Units	Air dried lumber	Kiln dried lumber	Plywood	Veneer	Furniture parts	Total
Forestry subsystem							
Tree harvested	mln m^3/year	1.60	2.20	1.60	0.60	0.45	6.41
Logs output	mln m^3/year	0.32	0.44	0.32	0.12	0.09	1.29
Wood waste loss	mln m^3/year	1.28	1.76	1.28	0.48	0.36	**5.12**
Timber industry subsystem							
Logs input	mln m^3/year	0.32	0.44	0.32	0.12	0.09	1.29
Wood product output	mln m^3/year	0.11	0.16	0.16	0.09	0.06	0.58
Wood product recovery	%	34	36	50	75	67	
Wood waste generated	mln m^3/year	0.21	0.28	0.16	0.03	0.05	0.75
Wood loss	%	66	64	50	25	33	
Total wood waste (Sum of forestry and timber industry subsystems wood waste loss)	mln m^3/year	1.49	2.04	1.44	0.51	0.41	6.00
% of total wood waste		25	34	24	9	8	100

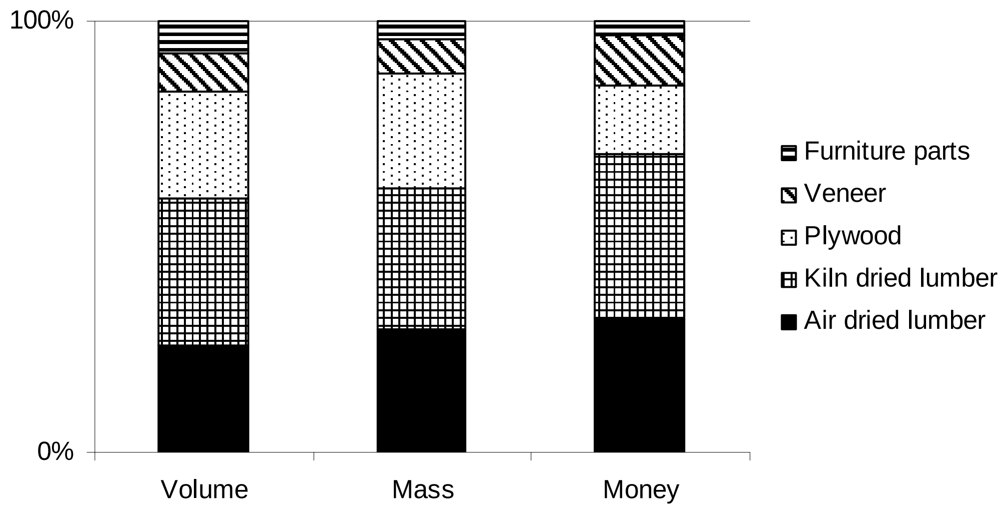

Figure 5.1: Influence of functional unit on wood waste impact results for 5 major production lines in Ghana's timber sector

Table 5.1 Present technology choices for a given process, wood waste type, possible causes of wood waste (WW) and estimated wood waste reduction (WWR) scenarios (S) for the forestry subsystem of the timber sector of Ghana

Process	Present equipment type	Wood waste type	Causative analysis	% WW output	Scenario 2	% WWR	Scenario 3	% WWR	Scenario 4	% WWR	%WWR Scenario 5 (=S2-4)
Harvesting	chainsaw	Tree branches, stumps, juvenile trees, undersize logs, off-cuts, sawdust	Unplanned harvesting schedules & lack of logistic systems leading to excessive wood waste. i.e. Technological and Management problems	50	Invest in harvesting and logistic systems to reduce wood waste	5	Plan control harvesting techniques to avoid excessive wood waste, Communicate regular reviews of wood resource availability and match to existing processing capacity and potential investments	5	Use mobile hogger to recover all wood waste after harvesting for recycling into wood composite boards	32	42
Skidding	Skidders, tractors	Juvenile trees	Unplanned skidding routes leading to excessive tree damage and wood waste. i.e. Technological and Management problems	20	Use of skidders for moving felled timber to suitable landing sites to avoid the destruction of juvenile trees	10	Plan skidding routes to avoid excessive wood waste	3	Recover all wood waste and hog for recycling	5	18
Processing & sorting & loading	Loaders, tractors	Off-cuts, sawdust, unsound logs (i.e. logs with big holes in heart)	Defects produced as a result of Technological and Management problems	10	Use log scanner systems for measuring shapes and internal properties of logs to ensure optimization of cross-cutting of stems	3	Train staff on wood waste managements in order to achieve attitudes change to improve efficient operation of machine and equipment	2	Recover all wood waste and hog for recycling	4	9
%				80		18		10		41	69

Table 5.2 Present technology choices for a given process, wood waste type, possible causes of wood waste (WW) and estimated wood waste reduction (WWR) scenarios (S) for the timber industry subsystem (Sawmilling) of the timber sector of Ghana

Process	Present equipment type	Wood waste type	Causative analysis	% WW output	Scenario 2	% WWR	Scenario 3	% WWR	Scenario 4	% WWR	%WWR Scenario 5 (=S2-4)
Log-yard & sorting	Loaders, cranes	Unsound logs (i.e. logs with big holes in heart)	Defects produced as a result of Technological and Management problems	5	Use log scanner systems for measuring shape and internal properties of logs to ensure optimization of borders of log classes based on order files	1	Improve timber storage and handling facilities to reduce wood waste. Improve communication during log sorting to feed the various unit processes. Control and optimize information and material flows in planning and production systems to minimize wood waste.	2	Recover all wood waste for recycling	1	4
Bucking & debarking	Chainsaw, hand tools	Barks, off-cuts & sawdust	Embedded stone or metal in the bark of timber may cause saw damage during wood processing.	10	Employ the use of scanners in log measurements to ensure accurate measurement and cutting. Employ the use of mechanical debarkers to safeguard saws and other equipment from undue wear and damage	3	Adhere to strict production specification orders to reduce wood waste.	2	Recover all wood waste for recycling	3	8
Head rig sawing	Band saw, frame saw	Slabs & sawdust	The use of thick saw blade i.e. Technological and Management problems	30	Computerize the monitoring of band saw displacements and the control of feed speed to reduce wood waste. Use thin saw blades to reduce wood waste	8	Use log carriage conveys to convey the log through the head-saw on which the log may be clamped and turned, so as to enable it to be presented to the head-saw in order to achieve the best sawing pattern	2	Recover all wood waste for recycling	15	25
Edging	Multiple edger	Sawdust, slabs, off-cuts & edged trimmings	The use of thick saw blade i.e. Technological and Management problems	10	Use thin saw blades to reduce wood kerfs thickness hence wood waste reduction	3	Ensure that machine vibration do not change machine settings. Ensure adequate maintenance of saw.	1	Recover all wood waste for recycling	5	9
Cross cutting	Radial, Pendulum type circular saw	Sawdust, off-cuts	The use of thick saw blade i.e. Technological and Management problems	6	Use thin saw blades to reduce wood kerfs thickness	1	Ensure that machine vibration do not change machine settings. Ensure adequate maintenance saw.	1	Recover all wood waste for recycling	3	5
Circular sawing	Bench saw	Sawdust, off-cuts	The use of thick saw blade i.e. Technological and Management problems	5	Use thin saw blades to reduce wood kerfs thickness	1	Ensure that machine vibration do not change machine settings. Ensure adequate maintenance saw.	1	Recover all wood waste for recycling	1	3
%				66		17		9		28	54

Table 5.3 Present technology choices for a given process, wood waste type, possible causes of wood waste (WW) and estimated wood waste reduction (WWR) scenarios (S) for the timber industry subsystem (Furniture milling) of the timber sector of Ghana

Process	Present equipment type	Wood waste type	Causative analysis	% WW output	Scenario 2	% WWR	Scenario 3	% WWR	Scenario 4	% WWR	%WWR Scenario 5 (=S2-4)
Jointer & moulder	Jointer & moulder	Sawdust, off-cuts	Jointer and moulder adjustment i.e. Technological and Management problems	20	Install modern Computer Numerical Control (CNC) machine tools to reduce wood waste.	5	Ensure adequate maintenance of machines and wood cutters.	1	Recover all wood waste for recycling	9	15
Planer & sander	Planer & sander	Sawdust, off-cuts	Planer and sander adjustment i.e. Technological and Management problems	13	Install modern Computer Numerical Control (CNC) machine tools to reduce wood waste.	5	Ensure adequate maintenance of machines and wood cutters.	1	Recover all wood waste for recycling	5	11
%				30		10		2		14	26

Table 5.4 Present technology choices for a given process, wood waste type, possible causes of wood waste (WW) and estimated wood waste reduction (WWR) scenarios (S) for the timber industry subsystem (Plymilling) of the timber sector of Ghana

Process	Present equipment type	Wood waste type	Causative analysis	% WW output	Scenario 2	% WWR	Scenario 3	% WWR	Scenario 4	% WWR	%WWR Scenario 5 (=S2-4)
Log-yard & sorting	Loaders, cranes	Unsound logs (i.e. logs with big holes in heart)	Defects produced as a result of Technological and Management problems	5	Use log scanner systems for measuring shape and internal properties of logs to ensure optimization of borders of log classes based on order files	1	Improve timber storage and handling facilities to reduce wood waste	2	Recover all wood waste for recycling	1	4
Bucking & debarking	Chainsaw, hand tools	Barks, off-cuts & sawdust	Embedded stone or metal in the bark of timber may cause saw damage during wood processing.	10	Employ the use of scanners in log measurements to ensure accurate measurement and cutting. Employ the use of mechanical debarkers to safeguard saws and other equipment from undue wear and damage	3	Adhere to strict production specification orders to reduce wood waste.	2	Recover all wood waste for recycling	3	8
Peeling & clipping	Peeling lathe clipper	Peeler core, sawdust, &clippings	The peeling block dimension closed to the heartwood causes wood breaks i.e. Technological and management problems	22			Ensure adequate machine maintenance and efficiency to reduce wood waste.	2	Recover all wood waste for recycling	15	17
Sawing & trimming	Circular saw	Sawdust, edge trimmings	The use of thick saw blade i.e. Technological and Management problems	10	Use thin saw blade	1	Ensure adequate machine maintenance and efficiency to reduce wood waste.	2	Recover all wood waste for recycling	5	8
Sanding	Sander	Sawdust	Sander adjustment i.e. Technological and Management problems	3			Ensure adequate machine maintenance and efficiency to reduce wood waste.	1	Recover all wood waste for recycling	1	2
%				50		5		9		25	39

Table 5.5 Present technology choices for a given process, wood waste type, possible causes of wood waste (WW) and estimated wood waste reduction (WWR) scenarios (S) for the timber industry subsystem (Veneer milling) of the timber sector of Ghana

Process	Present equipment type	Wood waste type	Causative analysis	% WW output	Scenario 2	% WWR	Scenario 3	% WWR	Scenario 4	% WWR	%WWR Scenario 5 (=S2-4)
Log-yard & sorting	Loaders, cranes	Unsound logs (i.e. logs with big holes in heart)	Defects produced as a result of Technological and Management problems	5	Use log scanner systems for measuring shape and internal properties of logs to ensure optimization of borders of log classes based on order files	1	Improve timber storage and handling facilities to reduce wood waste	2	Recover all wood waste for recycling	1	4
Bucking & debarking	Chainsaw, hand tools	Barks, off-cuts & sawdust	Embedded stone or metal in the bark of timber may cause saw damage during wood processing.	10	Employ the use of scanners in log measurements to ensure accurate measurement and cutting. Employ the use of mechanical debarkers to safeguard saws and other equipment from undue wear and damage	3	Adhere to strict production specification orders to reduce wood waste.	2	Recover all wood waste for recycling	3	8
Slicing	Slicing lathe	Slicing core, sawdust, veneer pieces, clippings	The slicing block dimension closed to the heartwood causes wood breaks i.e. Technological and managements problems	13					Recover all wood waste for recycling	10	10
%				25		4		4		14	22

Identification of relevant waste minimization measures

This section reviews 12 relevant waste minimization studies on the timber sector and related sectors in the context of the technological and process execution and management-based factors. Table 5.6 presents the results of these waste minimization studies. All these studies focus on different facets of waste minimization and collectively they address the objectives of sustainable development. Most of the reviewed studies aimed at analyzing the achievements of waste minimization concept from the perspective of industry and environmental policies. These studies distinguish 5 categories of improvement opportunities for waste minimization: good operating practices (GP), technology Change (TC), change in input material (CM), change in product (CP), waste recycling (WR) and waste reuse/recover (WRR).

Good operating practice

Good operating practice is a strategic management term for good production practices. According to Table 5.6, 6 out of the 12 studies employed good operating practices. These operating practices were implemented at relatively low cost, which were given as a good return on investment in a relatively short time. This good operating practice includes many procedural changes that can easily be implemented in many areas of industrial plant operation and forestry. The main specific aspects of good operating practices are: waste management, cost-accounting, inventory management, procedural scheduling, material handling improvements and loss prevention, waste stream segregation, and personnel education, communication, and involvement.

Technology Change

Technology change is the term used to describe environmentally sound technologies that are less polluting, uses all resources in a more sustainable manner and reduces wastes in a more acceptable manner than the technologies for which they were substitutes. Waste minimization option for technology change were seen as capital intensive and expensive and often had to undergo critical techno-economic and environmental scrutiny before selection (Babu et al. 2009). 3 out of the 12 studies used technology change to address waste minimization (Table 5.6). The technological changes were seen to address wastes at its source. Technological change is central to environmental action and has contributed to solving various environmental problems (Shin et al. 2008). According to Lall (1993), reduction strategies involving industrial technology and process-specific changes require a good understanding of the details of the industrial operation. Categories of technological changes to achieve source reduction include: process changes, equipment, piping or layout changes, and additional process automation.

Change in input material

Input material change is the means of finding environmentally friendly and economically low alternative to material input in production. 2 out of the 12 studies employed changes in input material to address waste minimization (Table 5.6). Materials of concern are chemicals where scientific evidence shows probable serious long-term effects to humans or the environment and for which there exists or potential future legislation that may restrict their use. These compounds include substances that persist in the environment, and their accumulations are toxic to life for example carcinogens substances known to cause asthma, and ozone-depleting substances. Recently, changes in input material are an active and growing area of industrial research and development (Daian and Ozarska 2009).

Change in product

The amount of waste generated from the manufacturing of a product may be reduced by the substitution of one product for another or altering the composition of the product. According to Table 5.6, 6 out of 12 studies used changes in product to address waste minimization. Change in product for small-volume products with strict sustainable forest management policy hold the potential to slow-down the pressure on tropical forest (Eshun et al. 2010a). Therefore, change in product in this direction holds a promising future in terms of sustainability for the timber sector.

Waste recycling and reuse

Waste recycling is the use, reuse or reclamation of all or part of wastes after they have been generated. Recycling is primarily considered to reduce the use of virgin natural resources. Apart from conserving natural resources recycling has the additional benefit of avoiding wastes associated with primary production and thus limits pollution (Reijnders 2000). Recycling and reusing are emerging as potential solutions for reduction of waste and depletion of natural resources caused by the mass production and mass consumption (Kim et al. 2009). According to Table 5.6, 11 out of the 12 studies used recycling and reuse to address waste minimization. Recycling and reuse option seems to be the most preferable waste minimization measure following source reduction.

The reviewed list of waste minimization measure provides representative information for wood waste minimization strategy to reduce the environmental impact in the timber sector in general. There is a need to decide on a list of waste minimization measures to reduce the environmental impact of the timber sector in Ghana. Since there is presently no wood waste recycling plant in Ghana, wood waste recycling measure in Ghana will eventually lead to change in products and therefore change in products measure was not considered. A change in input material was seen not to be relevant measure to consider since the study focuses mainly on wood waste. Looking at the sustainability issues in the timber sector of Ghana as described by Eshun et al. (2010b). The best options to reduce the environmental impact and conserve the natural resource from been depleted are technological changes, good operational practices and recycling measures. These selected wood waste minimization measures have the potential to also address process execution/management based factors and technological based factors which was identified in section 3.1 as the major causes of wood waste in the timber sector.

Scenarios analysis

Scenario analysis is an important tool used in environmental systems analysis, and can be defined as typical descriptions of alternative images of the future, that reflect different perspectives on, present and future developments (Alcamo 2001). In this study, scenarios are used as a tool to provide a picture of implementing the selected waste minimization in the future. A number of scenarios are analyzed based on the selected waste minimization measures to reduce the environmental impact in the timber sector of Ghana.

We propose broadly 5 scenarios for the introduction of wood waste minimization measures to reduce the environmental impact in Ghana:

Scenario 1 - No wood waste minimization measure

This scenario is the business as usual scenario and the worst of all the scenarios for the timber sector of Ghana. According to this scenario, if no wood waste minimization measures are implemented to reduce the environmental impacts in the timber sector, the sector will risk folding up in the near future. Moreover, the annual wood waste production of about 6 million m^3 is likely to deplete the natural tropical forest in the year 2025, if continued (Eshun et al. 2010a).

Table 5.6: Overview of 12 relevant waste minimization measures studies on the timber sector and related sectors to identified the country where the study was performed and the waste minimization measure used (x).

Industrial sector	Research areas	Country	GP	TC	CM	CP	WR	WRR
Timber (Daian and Ozarska 2009)	Wood waste management practices and strategies to increase sustainability standards in wooden furniture manufacturing sector	Australia				x	x	x
Timber (Okuneye et al. 1986)	Forestry residues, wood waste and fibreboard production and possible use	Nigeria				x	x	x
Timber (Dionco-Adetayo 2001)	Utiilization of wood waste	Nigeria	x			x	x	x
General (Tsai 2010)	Industrial waste reuse and pollution prevention	Taiwan	x				x	x
Timber (Liu 2003)	Waste minimization at a nitrocellulose manufacturing facility	Taiwan	x	x		x	x	x
General (Bai and Sutanto 2002)	The practice and challenges of solid waste management	Singapore					x	x
General (Jin et al. 2006)	Solid waste management: Practices and challenges	China					x	x
General (Hopper et al. 1993)	Solid industrial wastes and their management	Spain					x	x
Timber (Hogland and Stenis 2000)	Assessment and system analysis of industrial waste management	Sweden	x				x	x
Wine (Musee et al. 2007)	Waste minimization	South Africa	x	x	x	x	x	x
Metal (Babu et al. 2009)	Waste minimization	India	x	x	x	x		
Timber (Obata et al. 2006)	Wood waste recycling	Japan					x	x

GP= Good operating practices, TC= Technology Change, CM= Change in input material, (CP) = Change in products WR= Waste recycling, WRR= Waste reuse/recover

Scenario 2 - Technological change

This scenario is where the timber sector implements technology change to minimize wood waste so as to reduce its environmental impact. Technological change is very expensive and has changed timber sector operations significantly in recent years (Shin et al. 2008). The adaptation of technological changes in the timber sector of Ghana will reduce wastage and other environmental impacts and add value by improved timber harvesting techniques and production recovery rate. In the application of technology in the timber sector there is the need to ensure that the technology used is appropriate to the developmental goals of the recipient country or region and to local socio-economic conditions. The appropriateness of such technology must be assessed in terms of its impact on resources relative to local factor costs, the size and preferences of local markets, the skills of local labor and management, the availability of raw and semi-finished goods, and in relation to the present and future capacity for local planning and implementation.

According to our study, implementing scenario 2 reduces overall wood waste impact in the forestry subsystem by 13% (Figure 5.2). For the timber industry subsystem, technological changes reduce wood waste production of air dried and kiln dried lumber by approximately 16%. Wood waste from plywood production is reduced by 6% and veneer production by 9%. Wood waste from furniture part production is reduced by 19% (Figure 5.3).

Scenario 3 - Good operational practice

This scenario is where the timber sector implements good operational practices to minimize wood waste. Good operational practice deals with the planning, implementing and controlling of the industrial production processes at all stages of the product lifecycle. The production management team needs to have a certain level of technological knowledge and skills to bring about that planned output levels, cost levels and quality objectives with the aim of reducing wood waste. There is also a need to train workers to upgrade their skills to meet new technological challenges that might arise in the area of production. This will also help to increase technical competence to manage and invest in more efficient machinery which will go a long way to improve sustainable production. If capital intensive measure may be inappropriate for Ghana because of its high costs, then the use of good operational practices may be more appropriate to reduce environmental impact of the timber sector. The use of these measures to increase environmental performance could be an important additional source of the savings needed at a low investment cost. This approach would take a long time, looking at the current sustainability issues in Ghana.

According to our study, implementing scenario 3 reduces overall wood waste impact in the forestry subsystem by 7% (Figure 5.2). For the timber industry subsystem, good operational practices reduce wood waste of air dried and kiln dried lumber by approximately 8%. Wood waste from plywood production is reduced by 12% and veneer production by 9%. Wood waste for furniture part production is also reduced by 4% (Figure 5.3).

Scenario 4 - Recycling, reuse and recovery

This scenario employs recycling, reuse and recovery of wood wastes as a potential wood waste minimization strategy to reduce environmental impact in the timber sector of Ghana. Looking at the sustainability issues in Ghana, this scenario promises to be a potential solutions for reduction of waste and depletion of natural resources (Kim et al. 2009). The availability of about 6 million m^3 of wood waste per year the timber sector promises to be an ideal material resource for recycling in Ghana. The following are some ways wood waste from the timber sector can be recycled or reused: For example in hardboard, fiberboard and particleboard where wood shavings and chips are pressed under heat and pressure to form panels. Presently there is no wood waste recycling opportunities in Ghana. This opportunity will help create additional employments for the local people to reduce the pressure on the forest for illegal alternative for income.

According to our study, implementing scenario 4 reduces the overall wood waste impact in the forestry subsystem by 30% (Figure 5.2). This amount of wood waste is a potential available resource for recycling into wood composite boards. For the timber industry subsystem, recycling, reuse and recovery measures was able to reduce wood waste production of air dried and kiln dried lumber by approximately 26%. Wood waste from plywood production is reduced by 32% and veneer production by 32%. For furniture part production recycling, reuse and recovery measures reduce wood waste by 27% (Figure 5.3).

Scenario 5 - Combination of technological change, good operating practices and recycling

This scenario employs the combination of source reduction by technological change and good operational practices with recycling measures as a wood waste minimization strategy to reduce environmental impact of the timber sector. This scenario is the combination of scenario 2, 3 and 4. Although combining of scenario 2, 3 and 4 may overlap and lead to less reduction impact than the estimated (Tables 5.1-5.5). Scenario 5 promises to be an effective strategy to reduce environmental impacts in the timber sector of Ghana.

According to our study, implementing scenario 5 reduces the overall wood waste impact in the forestry subsystem by approximately 50% (Figure 5.2). For the timber industry subsystem scenario 5 reduces wood waste production of all the products output by approximately 50% (Figure 5.3). Scenario 5 happens to be the most effective measure to reduce wood waste impact in the forestry subsystem in the timber sector of Ghana.

The technical evaluation of a measure determines whether a proposed waste minimization measure will work for the specific application. A typical checklist for technical evaluation could be as follows: availability of equipment, availability of operating skills, space availability, and effect on production, effect on product quality, safety aspects, maintenance requirements and effect on operational flexibility.

In each scenario, once the decision to invest is made, there are well understood practices for monitoring the progress of the investment and signaling if the project is deviating from the set course. This involves a scrutiny of the project and it's costing by an internal or external team qualified to determine whether the proposal is not over designed or over complicated to provide the final product at the quality specified. According Allen (1997), real saving of the order of 5-10% of the capital investment can often be made using this technique.

Discussion

This study is a follow up of 3 earlier studies on the timber sector of Ghana (Eshun et al. 2010a, 2010b, 2011). These studies consistently identified minimizing wood waste as a major point of departure for reducing the environmental impact of the timber sector of Ghana. Eshun et al. (2010a) therefore quantified wood waste in the industry subsystem, but not from the forestry subsystem. Therefore, additional information about wood waste from forestry, and about the state of equipment/machinery and potential for wood waste reduction in the whole timber sector was established through interviews with experts, actual plant observations and reviewing of literature. This information was used for the identification of the sources and types of wood waste, the causative analysis of the wood waste, possible waste minimization measures. Scenarios analysis was then used for proposing and analyzing strategic planning to minimize wood waste and other environmental impacts in the timber sector of Ghana.

The method used was successful in minimizing wood waste and other environmental impacts in the timber sector. The results clearly show the differences of the wood waste minimization impacts between the various proposed scenarios and therefore serve the purpose of the study. This study has provided a useful insight in the effective wood minimization strategy to reduce environmental impact in the timber sector in Africa, particularly Ghana.

Tables 5.1-5.5 summarize results for the identification and quantification of wood waste sources, wood waste type and causative analysis of wood waste in the timber sector. Table 5.6 provides the summary of the review of waste minimization measures. Figures 5.2–5.3 provide the summary of the differences of the wood waste minimization impacts between the various proposed scenarios in the forestry and timber industry subsystems provided by experts from the timber sector in Ghana (Tables 5.1-5.5).

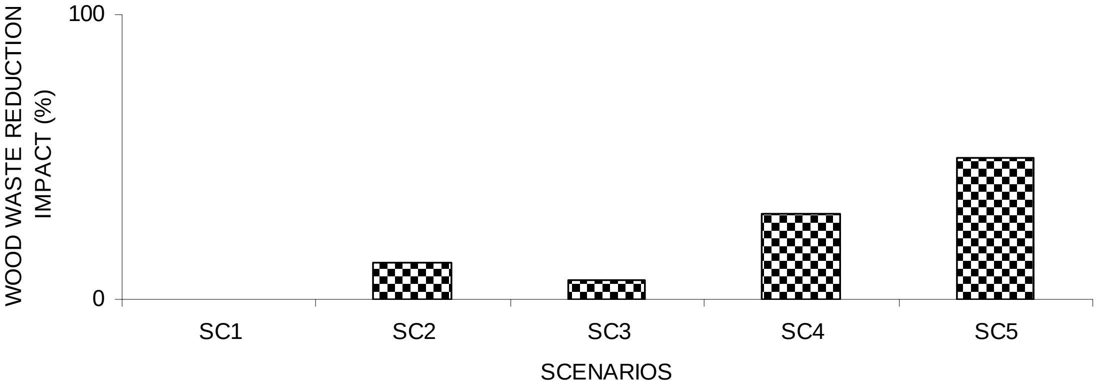

Figure 5.2: Summary of estimated individual wood waste reduction impact of all the scenarios of wood waste minimization measures in the forestry subsystem provided by experts from the timber sector in Ghana (Tables 5.1-5.5).

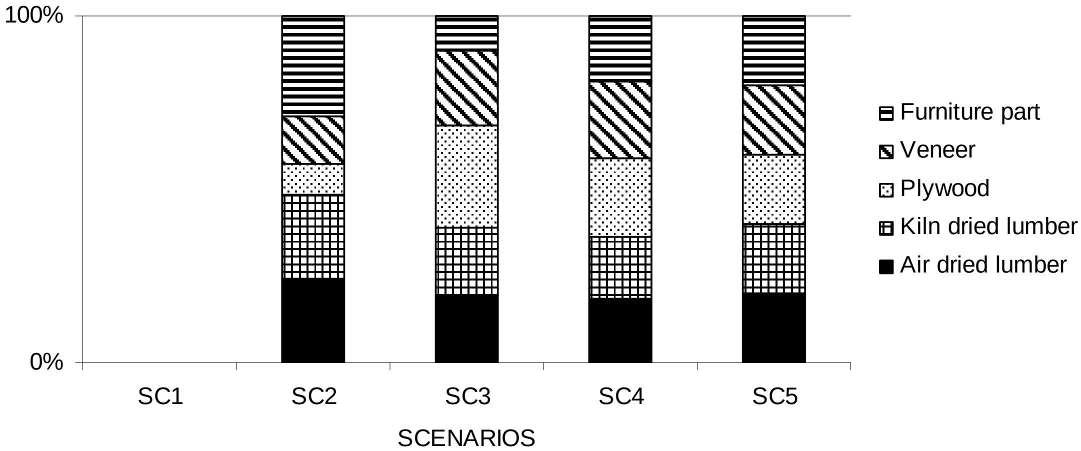

Figure 5.3: Summary of estimated individual wood waste reduction impact of all the scenarios of wood waste minimization measures in the timber industry subsystem provided by experts from the timber sector in Ghana (Tables 5.1-5.5)

In this study, 19 wood waste sources together with their possible causes were identified i.e. 3 in the forestry subsystem and 16 in the timber industry subsystem (Tables 5.1-5.5). One unique aspect of this study is its quantification of the wood waste in the forestry subsystem. According to Dionco-Adetayo (2001), about 0.8 m^3 of every 1 m^3 of tree cut and removed from the tropical forest goes to waste. The total forest wood waste in Ghana was estimated from combining this assumption with the quantitative results for the industry subsystem from Eshun et al. (2010a). The amount of forest wood waste was calculated to 5.12 million m^3 per year as shown in Table 5.0. This estimation then brings the total wood waste generated in both the forestry and timber industry subsystem to approximately 6 million m^3 per year. This forest wood waste is left in the forest and never used effectively whilst the industry wood waste is used either in steam production boiler for drying wood products or dumped on site. Wood wastage contributes to environmental impacts and also leads to the rapid depletion of the country's timber resources which constitutes a major setback to the sustainable management of timber sector.

According to our study, the factors relating to the causes of the generation of large amount of wood waste were observed to be:

Firstly technological-based, the industry's machinery installations, i.e. equipment, were seen to be obsolete and inefficient and therefore consume more wood than can actually be sustainably provided by the natural tropical forests. Wood conversion inefficiencies of round wood to sawn lumber or other final products were also seen to contribute to the causes of wood waste impact. According to Loehnetz et al. (1994), studies in some selected sawmills in tropical countries like Venezuela and Malaysia revealed that sawn wood of commercial dimensions recovery was 60-70% and 54.5%, respectively. When we compare our sawn wood recovery results of 34-36% to the Venezuela and Malaysia experience, the relatively low sawn wood recovery and high wood waste generation in Ghana is a source of concern (Table 5.0). This difference may be as a result of their improved technological and process execution/management based factors.

Secondly, process execution and management based factors relate to good operational practices or procedures, administrative, resource management and institutional maintenance practices were seen to be some important causes of wood waste generation in the timber sector. The improvement of production and management manpower skills in the timber sector is a potentially solution to this wood waste problems in the timber sector of Ghana.

Considering the sustainability issues in the timber sector of Ghana as described by Eshun et al. (2010b) and in the context of technology and process execution and management-based factors problems, technology change, good operating practices and recycling measures were seen to be the best relevant options to reduce wood waste and conserve the natural resource from been depleted.

Wood waste reduction data for Ghana's timber were limitedly available. The study therefore examined and estimated the current wood waste production in both the forestry and the timber industry subsystems. Wood waste reduction potential was estimated at each production stages based on the potential technology change, good operating practices and recycling measures required to reduce the current wood waste production. The wood waste reduction potential was best determined by the conversion efficiency of raw material to its final product through interviews with experts, actual plant observations and reviewing of literature. Although this estimation may introduce some uncertainties, it promises to be the most available and reliable wood waste reduction potential data as far as the timber sector is concerned.

The results of our study show that among the individual wood waste minimization scenarios, wood waste recovery, reuse and recycling (Scenario 4) was the highest wood waste reduction potential. However not withstanding, the combination of scenarios (Scenario 5 - recycling, technological change and good operating measures) reduce wood waste by approximately 50%. This scenario promises to be the most effective measure to drastically reduce wood waste in the timber sector. It must be noted that combining of scenario 2, 3 and 4 may overlap and lead to less reduction impact than the estimated. Care must be taken in using the results.

Our earlier study Eshun et al. (2011) established a very strong correlation between wood waste and land use and fairly positive correlation for the other 5 environmental impacts. The results indicate that wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss and the other impact categories. Moreover, when wood waste generated by the 5 wood products were further compared for 3 different functional units (m^3, kg or €). The chosen functional unit were sensitive to the wood waste impact results (Figure 5.1). Therefore, we conclude that the reduction of wood waste in the timber sector may reduce the other environmental impacts in the timber sector (Figure 5.2 and 5.3).

From the forgoing, there is a need to initiate waste minimization policy in Africa, particularly Ghana to provide more support and technical assistance for promoting and expanding environmentally sound technologies. This policy will effectively reduce pollution, improve productivity and enhance material efficiency. Studies show that the ability to create, acquire and adapt new technologies is a critical requirement for competing successfully in the international market (World Bank 2000, UNCTAD 2003). Improving process efficiency minimizes waste, thereby reducing emissions to the environment and saving money (Hilson 2000, Driussi and Jansz 2006, Shin et al. 2008).

According to the results of Eshun et al. (2010b), one major area that needs urgent attention for policy direction is the development of timber plantation industry to supplement resources from the natural forest to address the imbalance between supply and demand for the resource. The ultimate objective is to achieve a balance between utilization and conservation of the resource. Private sector led investment in commercial plantation and an increased participation of communities, individuals and other groups in small-scale tree planting activities together with an overall rehabilitation and restocking of the nation's forests (reforestation programmes) would ensure the sustainability of all forms of benefits derived from timber sector activities.

This systemic approach to wood waste minimization may serve as a guide for policy-makers as well as for companies in elaborating measures to reduce environmental impacts in terms of possible future developments in the timber sector in Africa and particularly Ghana.

Conclusions

Wood waste generation is inevitable either during felling of trees for log production in the forest or sawing processes of logs at different timber industry production lines. As the demand for wood products rises in a quest to meet the developmental drive of the society, the generated wood waste also increases and this increase presently overwhelms its utility and therefore creates environmental problems. This wood waste problem poses unique challenges to eliminate, reduce or manage effectively. A satisfactory solution to these challenges calls for a systematic integrated approach to minimize wood waste to reduce its concomitant environmental impacts.

Eshun et al. (2010a, 2010b, 2011) consistently identified minimizing wood waste as a major point of departure for reducing the environmental impact of the timber sector of Ghana. However, these studies quantified wood waste in the industry subsystem, but not from the forestry subsystem. Therefore, additional information about wood waste from forestry, and about the state of equipment/machinery and potential for wood waste reduction in the whole timber sector was established through interviews with experts, actual plant observations and reviewing of literature. This information was used for the identification of the sources and types of wood waste, the causative analysis of the wood waste and feasible waste minimization measures. Scenarios analysis was then used for proposing and analyzing strategic planning to minimize wood waste and other environmental impacts in the timber sector of Ghana.

According to our study, the total wood waste generated in both the forestry and timber industry subsystems amounted to approximately 6 million m^3 per year. This forest wood waste is left in the forest and never used effectively whilst the industry wood waste is used either in steam production boiler for drying wood products or dumped on site. This wood waste contributes to environmental impacts and also leads to the rapid depletion of the country's timber resources which constitutes a major setback to the sustainable management of timber sector. The factors relating to the causes of the generation of this large amount of wood waste were observed to be technological-based and process execution and management based factors.

In view these factors, 12 relevant waste minimization studies on the timber sector and related sectors were reviewed to help reduce the wood waste and other environmental problems in Ghana. Amidst other considerations, technology change, good operating practices and recycling measures were then selected as the relevant wood waste minimization measures. The study then combined the foregoing information for proposing and analyzing scenarios for the wood waste minimization as a strategic planning for the future of the timber sector.

The results of our study show that combining technological changes, good operational practices and recycling measures could reduce wood waste by approximately 50%. This scenario promises to be the most effective measure to drastically reduce wood waste and conserve the natural resource from been depleted.

Eshun et al. (2011) established a very strong correlation between wood waste and land use and fairly positive correlation for the other 5 environmental impacts. The results indicate that wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss and the other impact categories. Moreover, when wood waste generated by the 5 wood products were further compared for 3 different functional units (m^3, kg or €). The chosen functional unit were sensitive to the wood waste impact results (Figure 5.1). Therefore, we conclude that the reduction of wood waste in the timber sector may reduce the other environmental impacts in the timber sector (Figure 5.2 and 5.3).

The results provide a powerful tool to aid the development of sustainable waste management and environmental policy in the timber sector in Africa, particularly Ghana. Future studies must be directed towards developing good scientific research capacities in the timber sector of Africa, particularly Ghana. These developed capacities will improve data quality, facilitate better integration of scenarios and finally provide a more insight for wood waste reduction potentials in the timber sector. More reliable information on current tropical wood conversion efficiency and the factors that influence it will help in developing more accurate estimates of future improvements in technology and the influence of this technology on tropical timber resources.

Chapter 6: Discussion and Conclusions

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Introduction

The timber production in Ghana is associated with an increasing environmental burden in terms of use of resources, and production of emissions and waste (Ghana Gazette 2005). This has raised a serious concern in the region about deforestation, climate change, waste, soil erosion and large scale desertification (TED 1995). Deforestation has claimed an enormous toll through environmental damage, economic deterioration and human misery (TED 1995). The impact of deforestation is widespread, affecting the livelihoods of local people, disrupting important environmental functions and severely disrupting the biological integrity of the original forest ecosystem. This thesis explores the possible options and strategies to sustain and improve the environmental performance of the timber sector. Analyzing the environmental performance of the sector therefore provides an effective first step to enhance the sustainability of the timber sector in Ghana.

Over the last four years significant efforts have been made by the researcher to explore the possible options and strategies to sustain and improve the environmental performance of the timber. This thesis explores possibilities and limitations, as well as relevance of methodology needed to effectively deal with the environmental conditions in Ghana. The research started only with conceptual thought and these thought were elaborated to a sound framework. These frameworks were then used to assess the sustainability, life cycle assessment (LCA) and the improvement stages of this study.

The body of the thesis consists of chapters that are published as articles in well-known, peer-reviewed international journals in the field of forestry, LCA and cleaner production. The added effect of these chapters show that the conceptual thoughts in the present frameworks is largely consistent and gives a snap shot of the roots of the environmental problems in the timber sector and the way forward to effectively address them.

This chapter discusses the research questions raised in the introduction and draws conclusion and recommendations for further research. Section 6.1 discusses the overview of environmental assessment of the timber sector of Ghana. This discussion focuses on the sustainability of the timber sector, inventory analysis of the timber industry, life cycle impact assessment and wood waste minimization in the timber sector of Ghana: a system approach to reduce environmental impact. 6.2 conclude to what extent the research questions have been answered in this thesis, the institutional and policy implications of the synthesis and recommendation for further research.

Overview of environmental assessment of the timber sector

The overall objective of this thesis is to explore the possible options and strategies to sustain and improve the environmental performance of the timber sector in Ghana. To help adequately address this objective, four research questions were put forth: (1) Is the timber sector in Ghana sustainable? (2) What is the most dominant environmental pressure for the five major production lines in the Ghanaian timber industry, and what is the influence of the choice of functional unit? (3) What does the most dominant environmental pressure contribute to the life cycle impact of the timber sector in Ghana?, (4) Which potentials improvement options and strategies are available for reducing the major environmental impact in the Ghanaian timber sector? The discuses follow the stages used to address the four research questions.

Stage 1: Sustainability of the Ghanaian timber sector

Recently, the concern about environmental impacts has gone beyond relying on existing national regulation because international markets are increasingly demanding environmentally sound products (Eshun et al. 2010a). The values that international markets hold in relation to forests products can be powerfully expressed through their purchasing behavior. The ethics of consumption choices has increasingly been expressed through various certification schemes, in the case of tropical forestry since the early 1990s (ITTO 2005, Cashore et al. 2007, Cubbage et al. 2010). Most certification schemes allow consumers to choose timber products which has been sourced from forests deemed to be managed sustainably. Therefore effective integration of life cycle thinking in the timber sector is considered as a critical success factor for more sustainable industrial models (Ometto et al. 2006, Swarr 2006, Huang et al. 2007, Sundkvist and Finnveden 2007, Lilja and Liukkonen 2008, Rau and OuYang 2008).

There are a number of frameworks of sustainability assessment methods that evaluate the performance of companies (WBCSD 1997, GRI 2002, OECD 2002). It is interesting to note that companies have been struggling to come into consensus on key performance indicators that describe causal linkages that can be leveraged to drive sustainability initiatives (Epstein and Roy 2001). It is necessary to move beyond the need for a consensus on definitions and quantified measures and focus on developing a practical process worth understanding (Frame and Brown 2008).

To help decision makers in this study, it was useful to use a composite sustainable approach, linking many sustainability issues and so reducing the number of decision-making criteria and time that need to be considered. This study therefore adapted the method used by Sulser et al. (2001) in assessing biophysical sustainability in agriculture systems in Northern Ecuador and recommended it as quick, easily applied and effective assessment process. This method use structured closed-ended questionnaire, followed by in-depth personal interviews with selected stakeholders. Responses on economic, social and environmental consequences are then measured by sustainability indicators on a three point Likert scale (good, moderate and bad). The Likert scale measures responses to a statement and is most widely used in survey research (Likert 1932, Sulser et al. 2001, Skevington et al. 2004). This scale has gained popularity in recent research mainly due to its simplicity and reliability. This makes the Likert scale a more appropriate tool for this stage of this thesis. The results of this study are then used as basis for identifying sustainability gaps that need to be bridged in order to reduce the total environmental burden.

The results indicate that the sustainability of the timber sector is negative. This is because economic development policies in formal timber sector of Ghana mainly promoted production and export of primary wood products with the neglect of the wood supply needs of the local market. This negligence of the local market amongst others resulted in illegal chainsaw activities (informal sector) to supplement the local demand for wood. The pervasiveness of this informal sector activity has created an aggressive exploitation and unsustainable use of the forest resources in Ghana. This aggressive exploitation of the forest resources has created a sustainability gap which is expected to be widened if major policies are not implemented in the Ghanaian timber sector.

The foregoing development unfortunately represents an example of the so-called “tragedy of the commons”. Such tragedy is a dilemma arising from the situation in which multiple stakeholders, each driven by their short-term self-interest, will ultimately deplete a collective but limited resource. This is obviously not in anybodies long-term interest (Hardin 1968). According to Eshun et al. (2010a), this short-term self-interest of each stakeholder will lead to complete deforestation in 2025 at the present rate of exploitation.

In similar studies, Onuche (2010) explores the link between sustainability, poverty and global warming. Their study considers poverty as a key factor in the problem of the sustainability of forest resources in Nigeria. It then suggests a number of alternative solutions including the enactment and enforcement of progressive forest laws, a participatory approach, as well as the encouragement of the practice of agro-forestry to sustain the forest resources and reduce contribution to climate change.

Agyeman et al. (2003) also examines the interconnection between environmental justice and sustainability and their practical application within an urban setting. They argue that without a focus on justice and equity, sustainability will not have a lasting impact on quality of life. Their claims are based on the premise that practical, community-based initiatives to address environmental justice and sustainability concepts are the true test case for their theoretical compatibility.

The studies of Onuche (2010) and Agyeman et al. (2003) together with Eshun et al. (2010b) point to the fact that there is a policy failure in the timber sector. These developments constitute a setback to sustainable management. This policy failure implies there is an urgent need to develop policies to address the current economic, social and environmental impacts in the timber sector. Efforts to improve its sustainability can only be effective if done correctly. The order and transparency of reforms in the timber sector is vital to the successful recovery and sustenance of the tropical natural forest base.

The results confirm that sustainability indicators can be useful in quantifying the sustainability of the timber sector in Ghana. The advantages of the application of sustainability indictors to the timber sector in Ghana are three fold. First, these indicators provide very useful messages regarding the sustainability of Ghana’s recent development. The economic, social and environmental indicators indicate a development path that is not sustainable and do indicate an alarming situation. Second, they yield a set of widely diverse policy implications which need urgent attention. Third, provides available data and accessibility to local information. However, a disadvantage is the use of simple indicators as a means of following changes in complex systems for which data is not easily available and can represent characteristics of importance for the timber sector in Ghana. These may introduce uncertainties in the results.

The novel aspect of this study is the effort in bringing together the collection of issues relating to sustainability and linking it to environmental impact in the timber sector of Ghana. This integrated study has provided understanding of the sustainability gap that has been created as a result of competition between the formal and informal timber sector in the quest for raw material supply. The solution provided in this study will help bridge the sustainability gap in order to reduce the total environmental burden of the timber sector.

Stage 2: Inventory analysis of the timber industry in Ghana

This study takes care of research question (2): What is the most dominant environmental pressure for the five major production lines in the Ghanaian timber industry, and what is the influence of the choice of functional unit?

In this study, the first and second phases of LCA are applied. To accomplish the above research question, questionnaires were administered to a selection of 30 timber companies in Ghana. Information data base was obtained from both primary and secondary sources from the forestry and timber industry subsystems in Ghana and other scientific literatures. In this thesis, the major source of uncertainty is data availability. Particularly emission factors from literature were used that may not be necessarily relevant to African tropical environmental conditions, and particularly not for the timber sector in Ghana. This situation may contribute to uncertainty in the results. According to Walker et al. (2003), all environmental systems analysis studies are prone to uncertainties. The source of uncertainty include: context uncertainty, method uncertainty, input uncertainty, parameter uncertainty and result uncertainty.

In this study, a life cycle inventory (LCI) was compiled within the process boundaries. This LCI covered five timber production lines, namely air dried lumber, kiln dried lumber, plywood, veneer and furniture parts. These products constitute about 90% of the total timber products export in Ghana. The novel aspect of this study is that most LCA studies focus on just a single production line for e.g. plywood production (Wilson and Sakimoto 2005), sawmill production (Milota et al. 2005), forestry (Johnson et al. 2005, Lippke et al. 2005), veneer production (Wilson and Dancer 2005). This study focuses on a combination of production lines such as forestry, sawmill, plymill, veneer and furniture mill to achieve a higher level of integration of assessing the environmental performance in the timber industry in Ghana. Each selected company covers one product line only. This means that companies with more than one product line were excluded from the sample. This was done to enhance data processing. No allocation rules were needed since the level of process detail was sufficient to avoid multiple output processes. The collected data were converted into total annual average values, and for a fair comparison on the national level extrapolated to reflect the national average data for all one hundred and four (104) active companies.

The LCI focuses on the material use, energy use, emissions of pollutants, and land use. The functional unit provides the reference to which the environmental inputs and outputs of a product system are related (ISO - 14044 2006). In this study, the different services were expected to be insufficiently expressed by the usual functional unit of 1 m^3 of product produced. Two additional functional units were selected. One defined as 1 kg of product produced and the other as 1 euro of product produced. The results for all functional units and products are expressed at the same moisture content. The results of this stage are used as a basis for the analysis in subsequent phases.

The results indicate that carbon dioxide (CO_2) emissions by the timber sector activities per year dominated overall greenhouse gases emissions in the timber sector (changes in carbons storage related to land use changes not included). Main contributors here are the kiln dried lumber, plywood and veneer production lines. Biomass combustion in steam production boiler, which was mainly used for drying wood products, accounted for the highest energy usage. The results of this study are very useful and revealing the current greenhouse emissions inventories from the timber industry.

One factor that is contributing enormously to the rapid depletion of the country's timber resources is wastage of wood during log processing. It was found that these enormous amounts of wood wastes are generated in the timber industry as a result of its low timber production recovery. Wood waste thus constitutes a major setback to the sustainable management of the timber sector. These results will also be interesting for decision makers on future projects especially large scale intensive forestry plantation project to augment the depleted stock of timber resources.

It was concluded that, if the degradation trend continues in the same speed, then the total forest production area would be gone by the year 2025. Land use changes were also identified as a critical issue and require an urgent attention. This situation could exert a number of influences on the local, regional and global climates through the release of stored carbon contributing to the rise in atmospheric CO_2.

According to the results of the sustainability study Eshun et al. (2010b), and the inventory study Eshun et al. (2010a), one major area that needs urgent attention for policy direction is the development of timber plantation industry to supplement resources from the natural forest to address the imbalance between supply and demand for the resource. The ultimate objective is to achieve a balance between utilization and conservation of the resource. Private sector investment in commercial plantations and increased participation of communities, individuals and other groups in small-scale tree planting activities together with an overall rehabilitation and restocking of the nation's forests would ensure the sustainability of all forms of benefits derived from timber sector activities.

The chosen functional units' (volume, mass and money unit of timber product) plays a crucial role in the environmental comparison of the different production line. The money-based functional unit, which also seems more appropriate for the different products considered, favors the value-added. Value-added products with strict sustainable forest management policy hold a promising future in terms of sustainability for the timber industry in Ghana.

Despite the fact that we did not perform a formal sensitivity analysis, the data obtained in this LCI clearly shows the difference between the product lines and therefore serve the purpose of the study. All data used in this study was considered to be the best available data. The information from an LCI results does not allow concluding on whether and to what extent a single inventory parameter contributes to the environmental problems. The results of this phase was used as a basis for the analysis in subsequent phases i.e. Life cycle impact assessment.

Stage 3: LCA of the timber sector in Ghana: Preliminary Life Cycle Impact Assessment (LCIA)

This study takes care of this research question (3): What is the contribution of the most dominant environmental pressure to the life cycle impact assessment for the timber sector in Ghana? This study uses the LCI study of Eshun et al. (2010a) as a starting point for an additional LCIA. The LCIA aims at evaluating the significance of potential environmental impact of the results of inventory analysis (the second phase of an LCA), within the framework of the defined goal and scope of the study (first phase on an LCA) (ISO - 14044 2006).

The LCIA phase consists of mandatory and optional steps. The mandatory steps of the LCIA approach are made up of the following: (1) the selection of impact categories, category indicators and characterization methodology, (2) the assignment of LCI results to the selected impact categories (classification) and (3) the calculation of category indicator results (characterization). The additional optional steps of the LCIA approach consist of the following: (4) normalization, which expresses potential impacts in ways that can be compared, (5) grouping, i.e. sorting and possibly ranking of the impact categories, (6) weighting, i.e. converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices, and (7) data quality analysis i.e. to better understand the reliability of the collection of indicator results and the LCIA profile.

The use of the optional steps depends on the goal and scope of the LCA studies, because they are not allowed in comparative LCAs which results are to be disclosed to the public (ISO - 14044 2006). The optional steps, and specifically the weighting step, have been criticised for their subjectivity. Goyal and Deshpande (2001) therefore argued, for example, to increase accuracy by defining clear and exhaustive criteria, based on experts' opinions, to specify the precise weights. We avoid in this study the optional steps and focus only on the mandatory steps in the LCIA phase.

Applying LCIA was found to be a useful to systematically determine all relevant environmental concerns and the contribution of the different subsystems in the timber sector to the overall environmental impact. It is worth noting that the life cycle impact assessments procedure itself can reduce uncertainty, since the stepwise approach allows for iteration.

An extensive literature search was carried out on forestry, timber and wood products LCAs to adequately select the relevant impact categories and characterization approaches to quantify the environmental impact from the most dominant environmental pressure in the life cycle of the Ghanaian timber sector. The results reveal that impact categories and characterization methodologies used in most LCIA show to take their basis in the environmental problems in Western countries, and mainstream characterization methodologies relate to how these problems manifest themselves in the western world.

Therefore, their LCIA approaches and characterization methodologies may not be necessarily relevant to African tropical environmental conditions, and neither not for the timber sector in Ghana. This situation hampers the reliability of the LCIA and points to a serious research gap in LCIA development in general. When a proper impact categories and LCIA approach are available for Africa, the improved quality of LCA results may better inform decision making in timber sector of Ghana.

Notwithstanding, a preliminary Life Cycle Impact Assessment (LCIA**)** was performed using carefully selected impact categories and the CML 2000 methodology together with the LCI results of Eshun et al. (2010a) to quantify global warming, acidification, eutrophication, photochemical oxidant formation, human toxicity, and wood waste impacts in the Ghanaian timber sector. The CML 2000 methodology happens to be the most internationally accepted and recognized impact approach in LCA. It uses mid-point indicators that are relatively transparent in the underlying physical modeling.

This LCIA, phase provides additional information about how much the most dominant environmental pressure contribute to the environmental impact of the timber sector in Ghana. Life cycle impact assessments done elsewhere might have similar results, but the percentage contribution to each impact category would differ, depending on the type of energy used, the electricity mix, the sources of raw materials and the type of technology used in the timber industry in a target country of study. However this work presents findings from an African tropic perspective, particularly Ghana and demonstrates the use of LCIA methodology in life cycle assessment.

Correlation and regression analysis was then performed to learn whether wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss and the other impact categories as well. The results establish a very strong correlation between wood waste and land use and a fairly positive correlation for the other 5 environmental impacts. The results indicates that wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss and the other impact categories.

The development of characterization for biodiversity loss was considered to be at an early phase (Udo de Haes et al. 2002, Dubreuil et al. 2007, Michelsen 2008). Therefore wood waste was used to address biodiversity loss issues in the timber sector. In Ghana, major categories of land-use exist such as agriculture, forestry and mining. These land use have tremendous impact on biodiversity. The most important areas where human activities with biodiversity are intrinsic are agriculture and forestry. These activities result in reduced species level through over-harvesting of timber and forest clearing for agriculture fields. Some of the traditional timber tree species that have been endangered in the timber sector as a result of rapid loss of biodiversity include: chloroplora, Afromorsia, mahoganies and Sapeles (Tufuor 2005). We therefore conclude that an increase in wood waste is directly proportional to land use and hence biodiversity loss in the timber sector of Ghana.

The established correlation is very useful for a next waste minimization analysis, and evaluation of emerging technologies at early stages of decision making in the Ghanaian timber sector. The results will also serves as a comparison tool for industry improvement and a benchmark against competing products and materials. In addition, it will provide tools for the corrugated industry to use in performing consistent calculations irrespective of the country.

It is critical that the three studies of Eshun et al. (2010a, 2011) are pioneering a field not yet explored, since the correct impact indicators are not yet developed or adapted to tropical conditions.

Stage 4: Wood waste minimization in the timber sector of Ghana: a systems approach to reduce environmental impact

This study is a follow up of three earlier studies on the timber sector in Ghana (Eshun et al. 2010a, 2010b, 2011). These studies consistently identified minimizing wood waste as a major point of departure for reducing the environmental impact of the Ghanaian timber sector. From the foregoing developments, wood waste minimization was identified as a potential hot spot for improvement options and strategies for reducing the major environmental impact in the timber sector in Ghana. This study takes care of this research question (4): Which potentials improvement options and strategies are available for reducing the major environmental impact in the timber sector in Ghana?

This study takes care of research question 4. A system approach through interviews with experts, actual plant observations and reviewing of literature was used to obtain data for this study. This information was used for the identification of the sources and types of wood waste, the causative analysis of the wood waste, feasible waste minimization measures. Scenarios analysis was then used for proposing and analyzing strategic planning to minimize wood waste and other environmental impacts in the timber sector of Ghana.

This study identified 19 wood waste sources together with their possible causes i.e. 3 in the forestry subsystem and 16 in the timber industry subsystem. The total wood waste generated in the timber sector is about 6 million m^3 per year i.e. 5.12 million m^3 per year from the forestry subsystem and 0.8 million m^3 per year from the timber industry subsystem. This forest wood waste is left in the forest and never used effectively whilst the industry wood waste is used either in steam production boiler for drying wood products or dumped on site. This wood waste contributes to environmental impacts and also leads to the rapid depletion of the country's timber resources which constitutes a major setback to the sustainable management of timber sector. The factors relating to the causes of the generation of this large amount of wood waste were observed to be technological-based and process execution and management based factors. The technological-based factors relate amongst others to the type of equipment used, equipment sizes, and equipment efficiency that influence the quantity of wood waste generation. The industry's machinery installations, i.e. equipment, were seen to be obsolete and inefficient and therefore consume more wood than can actually be sustainably provided by the natural tropical forests. Wood conversion inefficiencies of round wood to sawn lumber or other final products were also seen to contribute to the causes of wood waste impact. Process execution and management factors relate to procedural, administrative, resource management and institutional maintenance practices. These factors were also seen to be some important causes of wood waste generation and other environmental impacts in the timber sector.

The need for the transfer and adoption of Environmental Sound Technology (EST) is evident as a result of the rapid depletion of the forest resource and the generation of enormous amount of wood waste in timber sector of Ghana. According to Adeoti (2002), the three most important drivers for technological choice of industry in Sub-Saharan Africa, particularly Nigeria are environmental policy, prevention of accidents and improvement of environmental image. In a similar study, Luken (2008) identified high implementation costs, no alternative process technology and lack of tradition/skills as the most important drivers for and barriers to environmentally sound technology adoption in developing countries. Interestingly, Adeoti (2002) also identified high cost of pollution control equipment, no compelling reason to invest in EST and lack of information about EST as the most important barriers to EST adoption in Africa. From the foregoing studies, the question now is how best can we design future industrial environmental management strategies that reduce the resource use intensity of production as well as protect the environment to sustain and improve the environmental performance of the timber sector in Ghana.

The results of our study show that combining technological changes, good operational practices and recycling measures could reduce wood waste by approximately 50%. This scenario promises to be the most effective measure to drastically reduce wood waste and conserve the natural resource from been depleted.

Our earlier studies established a very strong correlation between wood waste and land use and a fairly positive correlation for the other 5 environmental impacts. The results indicated that wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss and the other impact categories. Moreover, the wood waste generated by the 5 wood products were further compared for 3 different functional units (m^3, kg or €). The chosen functional unit influenced the wood waste impact results. However, we conclude that the reduction of wood waste in the timber sector may reduce biodiversity loss and the other environmental impacts in the timber sector.

Most of the fossil fuels consumption are used for fulfilling the energy demand involve in the production of materials, reduction of material use contributes significantly to the reduction of CO_2 emissions. Reduction of CO_2 emissions is very critical contribution to global warming impact reduction. Africa is likely to be hardest hit by the global warming impact because of its vulnerability and adaptive capacity (IPCC 2007b). Global warming leads to climate change. Climate change is the enhanced greenhouse effect attributed to human influence. The enhanced radiative forcing and thereby enhanced global warming is the primary effects caused by the increase of greenhouse gases in the atmosphere (Arena et al. 2003). These greenhouse gases are produced when wood waste are sent to landfills or dumped. The dumped wood wastes are exposed to other types of waste which prohibit wood from breaking down. Instead, it partially decomposes and releases methane gases. Methane contributes to air pollution, and also adds to global warming.

Recycling negates this effect, and also preserves live trees. These trees utilize carbon dioxide during photosynthesis, which help to offset greenhouse gases from other sources. Instead of passing into the ozone layer, the carbon is converted into oxygen by the tree. In the short term, this reduction in harvesting results in avoided greenhouse gas emissions through storage of carbon in forests. Wood waste reduction can significantly reduce greenhouse gas emissions. EPA (1994) estimated that 5% increasing in recycling rate would reduce greenhouse gas emissions by 10 million tons of carbon equivalent (MTCE). According to Eshun et al. (2011), The total global warming impact from global warming impact amounted to approximately 765 kton CO_2–equivalents per year. When we apply this estimation to our global warming impact value, the global warming impact will be reduced by 0.4 %.

Acidification refers to processes that increase the acidity of water and soil systems. Emissions of potentially acidifying substances (NO_x, SO_x, etc.) lead to deposition, which in turn can lead to damages to animal and plant populations (Arena et al. 2003). Hauschild and Wenzel (1998) quantifies this impact category as grams of SO_2-equivalent, by means of the hydrogen release potential. Acidification can be reduced remarkable in the timber sector of Ghana by energy savings through fossil fuel combustion.

Manufacturing wood products from recycled materials is beneficial because it typically requires less energy (diesel for transportation) than producing goods from virgin materials. In this way, if energy demand is decreased, the burning of fossil fuels and the emission of acidifying gases to the atmosphere will also decrease. Reducing waste, increasing energy efficiency and conserving forest at the same time save cost that can be taken to mitigate acidification and eutrophication. Overall, waste reduction has significant potential for decreasing acidifying gas emissions.

Application of advanced emission control technologies to polluting plants in the Europe reduces annual emissions of SO_2 by approximately 3,400 kilotonnes. This cut total European union emissions of SO_2 by approximately 40 per cent accounting to 1,500 euro per tonne of pollutant reduced (Barrett and Holland 2008). By applying this estimation to the timber sector of Ghana. The total annual acidifying impact from SO_2 and NO_X amounted to 1,179 ton SO_2 –equivalent per year. This would reduce total timber sector emissions of by approximately 0.02%, accounting to 0.75 euro per ton of pollutant reduced.

Biodiversity is considered a key component of ecosystems and as such a key determinant of ecosystem functioning. Several of the services provided by ecosystems which contribute significantly to human wellbeing are the direct products of biodiversity. On the other hand, biodiversity loss can, in one way or another, affect almost all services provided by ecosystems (MA 2005). Timber harvesting (Logging) often has devastating impacts on local forests, which serve as habitats for any number of plant and animal species. Cutting down trees destroys these habitats, and may leave wildlife exposed to weather or starvation. The logging process also destabilizes soil, leading to erosion and landscape changes. Recycling of wood waste for particleboard manufacture seems to be more favorable from an environmental point of view. In this sense, alternative renewable energies should be encouraged to avoid damage to resources.

Wastage of natural tropical forest resources is one of the downward spirals of poverty and environmental degradation in Ghana and Africa. The links between poverty, inequality, and environmental degradation needs to be critically considered by policy makers. Policies must be developed to stimulate economic growth that is forceful and at the same time socially and environmentally sustainable. The key to such a better economy is the development of products which create more value and have a better eco-efficiency as well.

In a nut shell, this integrated environmental assessment study provides the needed understanding of the knowledge gap existing in the timber sector of Ghana. The usefulness of this work for the timber sector in Ghana arises from individual finding in each research questions of the study from the understanding of sustainability, inventory analysis, environmental impact and exploring of wood waste minimization measures. All these studies have adequately addressed all the research question raised and provided a powerful tool to aid the development of sustainable, waste management and environmental policy in the timber sector in Africa, particularly Ghana.

Conclusions

Novel aspects of this thesis are (1) the sustainability assessment of the timber sector in Ghana, (2) the inventory analysis of its materials, land use, energy use, emissions and waste flows from and to nature, (3)the preliminary life cycle impact assessment of the timber sector and (4) analysis of wood waste minimization in the Ghanaian timber sector. These results contribute to filling the knowledge gaps identified in various studies and are helpful for the overall objectives of exploring the possible options and strategies to sustain and improve the environmental performance of the timber sector in Ghana (Eshun et al. 2010a, 2010b, 2011).

The research questions of this thesis were (1) Is the timber sector in Ghana sustainable?, (2) What is the most dominant environmental pressure for the five major production lines in the Ghanaian timber industry, and what is the influence of the choice of functional unit?, (3) What is the contribution of the most dominant environmental pressure to the environmental impact of the Ghanaian timber sector?, and (4) Which potentials improvement options and strategies are available for reducing the major environmental impact in the timber sector in Ghana?

The thesis shows considerable attempt and some limitations in the life cycle impact assessment addressing the entire research question put forth in the study. This assessment limitation stems from the fact that impact categories and characterization methodologies used in most LCIA show to take their basis in the environmental problems in Western countries, and characterization methodologies relate to how these problems manifest themselves in the western world. Therefore, their LCIA approaches and characterization methodologies may not be necessarily relevant to African tropical environmental conditions, and particularly not for the timber sector in Ghana. This situation hampers the reliability of the LCIA and points to a serious research gap in LCIA development in general. The generic approach that was used in this study helped improve the basis for decision-making in the timber sector of Ghana and clearly showed that LCA is a powerful tool for the assessment of environmental impacts of the timber sector in developing countries. However, there is an urgent need to include spatial differentiation into the LCIAs for developing continents, like Africa. Relevant impact categories, LCIA approaches and characterization methods to achieve this have to be further developed to address regional concerns and situations and to better reflect local variations. If used, we can then make a strong contribution to sustainability goals in Ghana and Africa.

Chapter 2 addresses the sustainability issues of the timber sector. The crux of this study lies in the sustainability gap that has been created as a result of aggressive competition between the informal and formal timber sectors for raw material supply. The study found that this aggressive competition is expected to be widened, if major policy interventions are not implemented and respected. The study concludes by suggesting a number of approaches to bridge this sustainability gap in order to make the timber sector sustainable**.**

Most sustainable policies are implemented without first understanding the underlying factors leading to environmental problems. This lack of understanding is the reasons for major sustainable policies failure in Ghana, and Africa more in general. Understanding and addressing the underlying factors to environmental problems put policy makers in a good picture on how to effectively deal with issues on sustainable development. Sustained high industry performance requires a balance between top-down results-driven performance improvement initiatives and bottom-up organizational learning and commitment. The results of the sustainability and LCA studies were effective strategic bridges to prioritizing and implementing sustainable initiatives projects that will create value for key stakeholders in the timber sector of Ghana, particularly Africa.

Chapter 3 starts the life cycle assessment study with an inventory analysis of the timber industry. The study identified land use and wood waste as the most dominant environmental pressure for five major production lines. Land use and wood waste pressures will eventually lead to complete deforestation in the year 2025 if major policies are not implemented. The study added that the choice of the functional unit (1m^3, 1kg and 1euro) influences the inventory results. The money-based functional unit was seen as more appropriate to favors the value-added products. The study concluded that the money-based functional unit holds a promising future in terms of sustainability for the timber industry in Ghana.

The enormous wood wastages are partly caused by the aggressive competition between the informal and formal timber sectors for raw material supply. It must be understood in recent times that tropical forestry is not about trees, but it’s about people. Therefore, there is a need for policy makers to modify how social values have been defined and applied over the years in the timber sector. This policy modification will go a long way to reduce or eliminate the aggressive competition between informal and formal sectors which is a major setback to sustainability in the timber sector. Such a move will enable policy implementers to be able to balance social sensitivity with technical and management skills.

One major area which needs urgent policy attention in the timber sector is the development of timber plantation industry to supplement resources from the natural forest. This policy will address the imbalance between supply and demand for timber resource as created as a result of the competition between informal and formal timber sectors. The ultimate objective is to achieve a balance between utilization and conservation of the resource.

The inventory analysis study compiled all inputs and outputs into a transparent inventory for the timber industry in Ghana. This will provide the industry with an overview of areas in which material and thus economic savings can be made for the good of both environment and the industry finances. It also makes it possible to get an overview of whether inputs could be substituted by less polluting materials. This is where life cycle thinking plays a major role in product policy development for a future sustainable industry. In the same vein, good data keeping in the Ghana timber industry will also help to build the required research capacity to develop local familiarity and competence in LCA techniques and applying these techniques will help to further certify tropical timber international markets.

Chapter 4 continues with the life cycle assessment study in Chapter 3. This Life Cycle Impact Assessment (LCIA) phase provides additional information about how harmful the contribution of the most dominant environmental pressure to the timber sector in Ghana. A correlation and regression analysis was performed between wood wastage and global warming, acidification, eutrophication, photochemical oxidant formation, human toxicity in the timber sector of Ghana. Wood waste happens to strongly correlate with land use as proxy for biodiversity loss, and also positively correlates with the other five impacts results. It concludes that wood waste production is a major driving force for biodiversity loss, and a sufficiently good single indicator for all other environmental impact in the timber sector of Ghana. This correlation was very useful for the subsequent wood waste minimization analysis and evaluation of emerging technologies at early stages of decision making in the timber sector of Ghana.

Chapter 5 identifies minimizing wood waste as a potential hot spot for improvement options and strategies for reducing the major environmental impact in the timber sector in Ghana. The results of the study show that combining technological changes, good operational practices and recycling measures could reduce wood waste by approximately 50%. This scenario promises to be the most effective measure to drastically reduce wood waste and conserve the natural resource from been depleted. The results also indicate that wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss and the other impact categories. Moreover, wood waste generated by the 5 wood products were further compared for 3 different functional units (m^3, kg or €). The chosen functional unit influenced the wood waste impact results. However, it can be concluded that the reduction of wood waste in the timber sector may reduce the other environmental impacts in the timber sector.

The combination of chapters used in this study give a snap shot of the roots of the environmental problems in the timber sector in Ghana and the way forward in addressing them to effectively enhance its sustainability. Advocating set of policies and actions without understanding linkage to environmental problems might jeopardize sustainable decision-making. Studies of this nature could support policy makers on the awareness of how and why diversity of values, viewpoints and actions on sustainability might assist on environmental issues in developing flexible and sound sustainability policies in Ghana, particularly Africa.

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Summary

The timber sector, i.e. forestry and timber industry is an important industry in Ghana. It provides a significant contribution to Ghana's foreign exchange earnings through wood products export, provides jobs and incomes for numerous local economies and communities. The timber production in Ghana is associated with an increasing environmental burden in terms of use of resources, and production of emissions and waste. This has raised a serious concern in the region about deforestation, climate change, waste, soil erosion and large scale desertification. The impact of deforestation is widespread, affecting the livelihoods of local people, disrupting important environmental functions and severely disrupting the biological integrity of the original forest ecosystem. For various reasons such as logging, the tropical forest in Ghana has been decreasing rapidly and significantly.

This concept of sustainable development has been incorporated in the past decade in several policy documents in the Ghanaian timber sector. It is questionable, however, whether these policies and agreements led to significant positive environmental and social changes. These environmental policies, however, are limited in terms of its implementation. There appears to be a gap between sustainability policies and their implementations in the Ghanaian timber sector. It is important to help policy makers and other stakeholders in the Ghanaian timber sector to identify, bridge this sustainability gap, sustain and improve the performance of the timber sector in Ghana.

The overall objective of this thesis is to explore the possible options and strategies to sustain and improve the environmental performance of the timber sector in Ghana. Analyzing the environmental performance of the sector therefore provides an effective first step to enhance the sustainability of the timber sector in Ghana. To achieve this objective, the following research questions are addressed in successive stages: (1) Is the timber sector in Ghana sustainable?, (2) What is the most dominant environmental pressure for the five major production lines in the Ghanaian timber industry, and what is the influence of the choice of functional unit?, (3) What does the most dominant environmental pressure contribute to the life cycle impact of the timber sector in Ghana?, and (4) Which potentials improvement options and strategies are available for reducing the major environmental impact in the timber sector in Ghana? The discuses follow the stages used to address the four research questions.

Chapter 1 provides a general introduction which describes the background of the study of the environmental assessment of the timber sector in Ghana and related international studies. This section is where the problem of the timber sector is formulated and the research questions of this thesis are introduced and the goal and scope definition and the methodological framework of the thesis are clarified.

Chapter 2 opens the study on the sustainability of the timber sector and addresses the research question (1) Is the timber sector in Ghana sustainable? To this end, sustainability framework method for participatory biophysical sustainability assessment was used. This method uses structured closed-ended questionnaire, followed by in-depth personal interviews with selected stakeholders. Responses on economic, social and environmental consequences are then measured by sustainability indicators on a three point Likert scale (good, moderate and bad). The Likert scale measures responses to a statement and is most widely used in survey research. The results of this study are then used as basis for identifying and bridging sustainability gap in order to reduce the total environmental burden.

The crux of this study lies in the sustainability gap that has been created as a result of aggressive competition between the informal and formal timber sectors for raw material

supply. The study found that this aggressive competition is expected to widened, if major policy interventions are not implemented and respected. The study concludes by suggesting a number of approaches to bridge this sustainability gap in order to make the timber sector sustainable.

Chapter 3 opens the life cycle assessment study with an inventory analysis of the timber industry and addresses the research question (2) what is the most dominant environmental pressure for five major production lines in the timber industry and its influence on the choice of functional unit in the timber sector in Ghana? To this end, Life Cycle Assessment (LCA) methodology framework was applied. LCA is a standardized method to comprehensively assess and evaluate the complex environmental burdens associated with the manufacturing of a product from resource extraction to end of life. This stage applies the first and second phases of LCA. This study focuses on the first and second phase in LCA that is often referred to as life cycle inventory (LCI). The LCI provided a comprehensive compilation and quantification of inputs and outputs in all the involved processes of activities for five major production lines in the timber industry. The five major production lines are air dried lumber, kiln dried lumber, plywood, veneer and furniture parts. The activities focus on the material use, energy use, emissions of pollutants, waste and land use changes. The study identifies land use and wood waste as the most dominant environmental pressure for five major production lines. The study found that land use and wood waste pressures will eventually lead to complete deforestation in the year 2025 if major policies are not implemented. The study also found that the choice of the functional unit ($1m^3$, 1kg and 1euro) was sensitive to the inventory results. The money-based functional unit was seen as more appropriate to favors the value-added products. The study concludes that money-based functional unit holds a promising future in terms of sustainability for the timber industry in Ghana.

Chapter 4 continues with the life cycle assessment study in Chapter 3 and addresses research question (3) what is the contribution of the most dominant environmental pressure to the life cycle impact assessment for the timber sector in Ghana? To this end, the third phase of LCA is applied i.e. Life Cycle Impact Assessment (LCIA) phase. This LCIA phase provides additional information about how harmful the contribution of the most dominant environmental pressure to the timber sector in Ghana.

To adequately select a relevant impact categories and characterization approach to address the contribution of the most dominant environmental pressure to the life cycle impact assessment for the timber sector in Ghana. An extensive literature search was carried out on forestry, timber and wood products journals. These results reveal that impact categories and characterization methodologies used in most LCIA indeed show to take their basis in the environmental problems in Western countries, and characterization methodologies relate to how these problems manifest themselves in the western world. Therefore, their LCIA approaches and characterization methodologies may not be necessarily relevant to African tropical environmental conditions, and particularly not for the timber sector in Ghana. This situation hampers the reliability of the LCIA and points to a serious research gap in LCIA development in general. The generic approach that was used in this study helped improve the basis for decision-making in the timber sector of Ghana and clearly showed that LCA is a powerful tool for the assessment of environmental impacts of the timber sector in developing countries. However, there is an urgent need to include spatial differentiation into the LCIAs for developing continents, like Africa. Relevant impact categories, LCIA approaches and characterization methods to achieve this have to be further developed to address regional concerns and situations and to better reflect local variations. If used, we can then make a strong contribution to sustainability goals in Ghana and Africa.

A preliminary Life Cycle Impact Assessment (LCIA) was performed using carefully selected impact categories and CML 2000 methodology together with the LCI results of the previous studies to quantify global warming, acidification, eutrophication, photochemical oxidant formation, human toxicity, and wood waste impacts in the timber sector of Ghana. CML 2000 methodology happens to be the most internationally accepted and recognized impact approach in LCAs and therefore uses mid-point indicators that are relatively transparent in the underlying physical modeling.

When correlation and regression analysis was performed for global warming, acidification, eutrophication, photochemical oxidant formation, human toxicity, and wood waste impacts in the timber sector of Ghana. Wood waste happens to be very strongly correlated with land use as proxy for biodiversity loss, and also positively correlated with the other five impacts results. The study concludes that wood waste production is a major driving force for biodiversity loss, and a sufficiently good single indicator for all other environmental impact in the timber sector of Ghana.

Based on the insight gained in the previous chapters, chapter 5 addresses the research (4) which potentials improvement options and strategies are available for reducing the major environmental impact in the timber sector in Ghana? Chapter 5 identifies minimizing wood waste minimization as a potential hot spot for improvement options and strategies for reducing the major environmental impact in the timber sector in Ghana. To this end, a system approach through interviews with experts, actual plant observations and reviewing of literature was used to obtain data for this study. This information was used for the identification of the sources and types of wood waste, the causative analysis of the wood waste, feasible waste minimization measures. Scenarios analysis was then used for proposing and analyzing strategic planning to minimize wood waste and other environmental impacts in the timber sector of Ghana.

The results of the study show that combining technological changes, good operational practices and recycling measures could reduce wood waste by approximately 50%. This scenario promises to be the most effective measure to drastically reduce wood waste and conserve the natural resource from been depleted. The results also indicate that wood wastes may function as a reasonable single indicator for land use as proxy for biodiversity loss and the other impact categories. Moreover, when wood waste generated by the 5 wood products were further compared for 3 different functional units (m^3, kg or €). The chosen functional unit were sensitive to the wood waste impact results. Therefore, it can also be concluded that the reduction of wood waste in the timber sector may reduce the other environmental impacts in the timber sector.

To conclude, chapter 6 discusses all the research questions raised in the introduction and the methodological contributions of this thesis in relation to other approaches in sustainability issues. This thesis therefore presents a first step in exploring the possible options and strategies to sustain and improve the environmental performance of the timber sector in Ghana. The understanding of the link between sustainability and environmental assessment can help to design and implement good and working sustainability policies in Africa. The presented research therefore contributes to the development of integrated policy support approaches, which aim at strengthening the sustainable management of the timber sector in Ghana. This research may serve as a guide for policy-makers as well as for companies in elaborating measures to sustain and reduce environmental impacts in terms of possible future developments in the timber sector in Africa and particularly Ghana.

Samenvatting

De houtsector, bestaande uit de bosbouwsector en de houtindustrie, zijn belangrijk voor Ghana. Deze sector draagt aanzienlijk bij aan inkomsten in buitenlandse valuta en voorziet in banen en inkomens voor talrijke lokale gemeenschappen. Deze houtsector wordt echter ook in verband gebracht met een toenemende milieubelasting als gevolg van onduurzaam gebruik van grondstoffen, afvalproductie, vervuiling en emissies van broeikasgassen. Hierdoor is men bezorgd over onder andere ontbossing, verwoestijning en klimaatverandering. Dit proefschrift gebruikt een levenscyclusanalyse om de milieuprestatie(s) van de Ghanese houtsector te bepalen en verkent mogelijkheden voor een verduurzaming van de sector. Na een algemene inleiding, beantwoord het proefschrift behandelt vijf onderzoeksvragen in vijf opeenvolgende hoofdstukken, gevolgd door en algemene synthese en conclusies.

Duurzaamheid in de Ghanese houtsector is in hoofdstuk 2 nog in zijn volle breedheid benaderd. Met behulp van een vragenlijst en aanvullende interviews zijn indicatoren voor economische, sociale en milieukundige duurzaamheid semi-kwantitatief in kaart gebracht. De agressieve competitie tussen de formele en informele houtsector in Ghana blijkt te leiden tot een duurzaamheidskloof. Deze zal naar verwachting groeien zolang beleidsinterventies en concrete veranderingen achterwege blijven. Het hoofdstuk geeft een aantal verbeteringssuggesties aan.

Hoofdstuk 3 en hoofdstuk 4 hangen samen. Hoofdstuk 3 maakt een zogenaamde "life cycle inventory" waarin het gebruik van grondstoffen, afval productie en emissies zijn gekwantificeerd. Hoofdstuk 4 voegt hier een zogenaamde "life cycle impact assessment" aan toe en vertaalt het gebruik van grondstoffen en de geproduceerde emissies en afval worden naar een groot aantal milieu-indicatoren. Zowel hoofdstuk 3 als 4 concluderen dat landgebruik en overmatige houtafvalproductie zonder verdere maatregelen zullen leiden tot een nagenoeg complete ontbossing in 2025. Hoofdstuk 4 stelt statistisch vast dat er een nagenoeg één op één relatie bestaat tussen houtafval en landgebruik, en een hoge correlatie met de andere indicatoren. In zowel hoofdstuk 3 als 4 is met drie functionele eenheden gewerkt (gebaseerd op geld, gewicht en volume van houtproducten). De keuze van de functionele eenheid beïnvloedt de resultaten, maar niet de conclusies van deze studie. De geld-gebaseerde functionele eenheid leidt tot een relatief lagere milieudruk van de duurdere houtproducten ten opzichte van de goedkopere houtproducten.

Hoofdstuk 5 bouwt voort op de resultaten uit hoofdstukken 4 en 5, en onderzoekt de mogelijkheden om de milieudruk van de Ghanese houtsector terug te brengen door vergaande reductie van de huidige extreme hoeveelheid houtafval. Verschillende afvalreductiemogelijkheden worden geïnventariseerd en geanalyseerd. Een combinatie van technologische veranderingen met een verbeterd operationeel management en recycling kan het houtafval met circa de helft terugbrengen.

Hoofdstuk 6 tenslotte bediscussieert de resultaten van alle hoofdstukken in relatie tot elkaar en trekt algehele conclusies. Dit proefschrift is een eerste belangrijke stap in de verkenning van de milieuprestatie en mogelijkheden voor milieukundige verduurzaming van de Ghanese houtsector. Begrip van de relatie tussen de milieuprestatie en verduurzaming in brede zin is van belang voor het ontwerpen van effectief duurzaamheidsbeleid in Afrika, en in Ghana in het bijzonder.

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Curriculum Vitae

John Frank Eshun was born on the 28th of June 1968 in Prestea, the western region of Ghana. From 1975 to 1982 he started his primary education at Prestea Goldfield International School. He completed his Ordinary Level General certificate Examination in Science at Ghana Secondary Technical School (G.S.T.S) in Takoradi, Ghana from 1983 to 1988. He then continued at the same school from 1988 to 1990 and had his Advance Level Examination in Science. From 1990 to 1991 he had his national service at Prestea Goldfield International School where he taught science and mathematics. After his national service he gain admission to read 3 years Physics at the Kwame Nkrumah University of Science and Technology (KNUST) where he had passed out with second class upper division in Physics. After his university education he had his one year national service education at G.S.T.S where he taught Physics. From 1996 to 1998 he had his MSc programme in Wood Technology and Industrial Management at KNUST. Immediately after his MSc education he gained employment at BMK particle board Ltd Takoradi as production assistance. In 2002, he finally resigned from BMK and took full time job as a lecturer and researcher in the Building Technology department at Takoradi Polytechnic. From 2002 to 2003 he went to Japan on Jica scholarship to read certificate in wood engineering. In 2007, he started his PhD programme in Environmental Systems Analysis Group at Wageningen University, The Netherlands

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C E R T I F I C A T E

The Netherlands Research School for the
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John Frank Eshun

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has successfully fulfilled all requirements of the
Educational Programme of SENSE.

Wageningen, 20 February 2012

the Chairman of the SENSE board

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- Development : understanding and applying multi-scale and participatory concepts and tools
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Oral and Poster Presentations

- SETAC Europe 19th Annual conference: Protecting ecosystem health: facing the challenge of a globally changing environment, 31 May – 4 June 2009, Goteborg, Sweden
- Environmental system analysis of the pressure exerted by the Ghanaian timber industry. Proposal presentation PhD research, 12 October 2007, Wageningen, The Netherlands
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