LIFE CYCLE ASSESSMENT FOR ENVIRONMENTAL PRODUCT DECLARATION OF TROPICAL AFRICAN MAHOGANY (KHAYA) LUMBER PRODUCED IN GHANA

REPORT

PREPARED FOR THE INTERNATIONAL TROPICAL TIMBER ORGANISATION (ITTO)

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1.0 Introduction

In recent times, the concern about environmental impacts has gone beyond relying on existing national regulation because international markets are increasingly demanding environmentally sound products (ITTO 2005). Most international timber certification schemes provide options to consumers to choose timber products which have been sourced from forests deemed to be managed sustainably (Brundtland 1987). Therefore, life cycle thinking has become a key focus in environmental integrated product policy and an effective integration of this concept in the timber sector is considered as a critical success factor for a more sustainable industry.

Life Cycle Assessment (LCA) is a tool to assess the environmental performance of, and to identify the environmental hotspots in a product chain. LCA is normally conducted for a product system from cradle to grave, by accounting all the environmental impacts from the resource extraction to end of product disposal based on a series of LCA standards created by International Organization for Standardization (ISO) namely, ISO 14040 and ISO 14044. LCA as defined by ISO 14040 and ISO 14044 is compiling and evaluation of inputs and outputs data, and the potential environmental impacts of a product system during the product's lifetime. The result may then be used for: identifying opportunities to improve the environmental aspects of a product at the various stages in its life cycle, decision making in industry and organization in the selection of products for application and marketing (e.g. an environmental claim, eco-labeling scheme or Environmental Products Declarations [EPD])

2.0 Review of Literature related to EPD and LCA of tropical wood products

2.1 General Review

Environmental product declarations are standardized documents used to communicate the environmental performance of a particular product based on LCA. EPD in general are covered by the ISO 14025 (2006) standard, however ISO 21930 (2007) and EN 15804 (2012) were reviewed to define how construction products should be assessed and reported using EPD. EN 15804 (2012) sets out how LCA should be used to consistently determine the environmental impacts associated with a construction product, generating results in a common format to enable building level assessment and comparison across Europe. Many hundreds of EPD are freely available from a number of European schemes and cover a very wide range of construction products, with most being for specific manufacturers' products. PAS 2050 (2008) takes a process life cycle assessment (LCA) approach to evaluate the Greenhouse gas(GHG) emissions associated with goods or services, enabling companies to identify ways to minimize emissions across the entire product system.

2.2 Review for Khaya lumber

There are different varieties of Khaya species. The main Khaya species in Ghana's forest are- *Khaya senegalensis, Khaya ivorensis, Khaya anthotheca, and Khaya grandifoliola.* The *Khaya* species is referred to as African mahogany. In terms of its distribution *Khaya* ranges across Central and Western Africa spanning about 19 countries. The tree is hearty and tolerates dry and wet climates as well as a variety of soil compositions. All species become big trees 30–35 m tall, rarely 45 m, with a trunk over 1 m in diameter, often buttressed at the base. Each region has different climates and different soil chemistry that can dramatically change the density and silica content of the wood. Khaya species has the best mixture of working properties and color consistency but even then you could find variations within this single species (Ghana Gazette, 2005).

African mahogany has the following characteristics:

- light red-brown color with pink overtones
- darker brown ribbon stripes that undulate from one end to the other
- interlocking yet tight grain pattern that won't fuzz with hand or power planing
- hard
- open yet tight pores with very few pin knots
- finishes beautifully with a lot of character from the striping
- holds carved and routed details very well without brittle edges

African mahogany is an important timber for furniture, indoor decoration, both in the solid and as veneer, high quality joinery for staircases, panelling, and domestic flooring, boat planking and cabins, banisters and handrails. The ivorensis species is said to provide the best surface-finishing of all the African Mahoganies and is a popular timber in East and West Africa for lorry bodies, construction work, and decking in boats apart from the normal uses of furniture.

2.3 Literature review on LCA studies

The environmental impact of the timber sector has received considerable attention from the research community. It is worth reviewing some selected environmental studies in Ghana. However, only one study on the Environmental Life Cycle Assessment to enhance the sustainability of the timber sector in Ghana by Eshun et al, 2012 stands out for the purpose. Outside of Ghana, several international studies exist on the identification and quantification of 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. 2009) and Spain by (Gasol et al. 2008, González-García et al. 2009). 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 (2006) and material and energy-related emissions by González-García et al. (2009). The environmental evaluation of products, production processes and services had profound implications for the timber sector.

3.0 Materials and Methods

In accordance with the ISO standard ISO - 14044 (2006), an LCA consists of four interrelated phases (Fig. 1), and are 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 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). 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 inventory 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, e.g. 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).

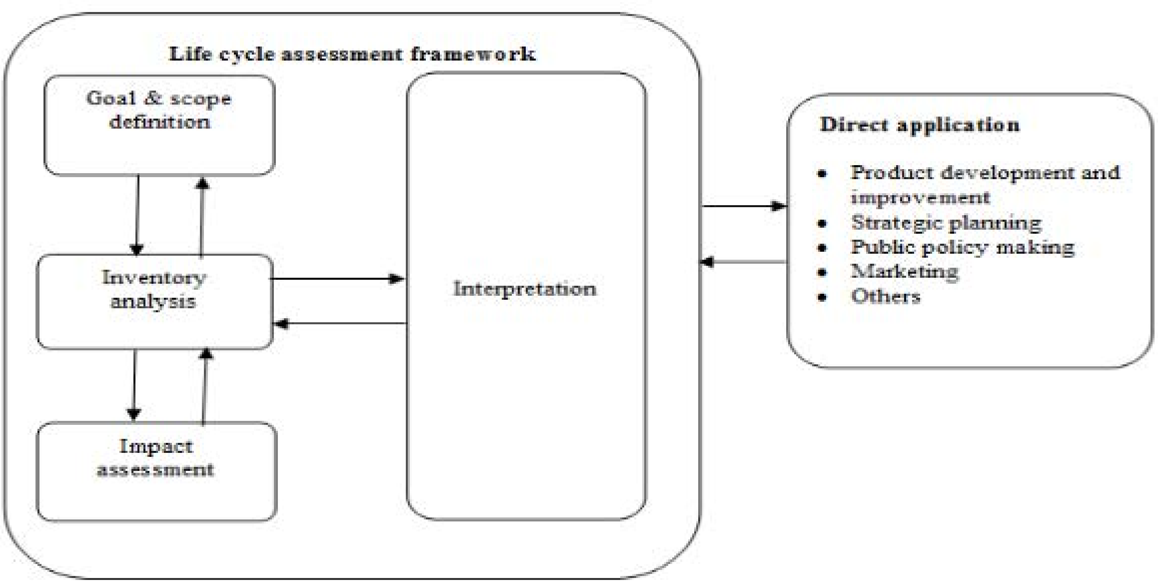

Fig. 1: The phases of an LCA according to ISO 14044 (2006)

3.1 Goal of the study

The overall objective of this study is to assess possible options and strategies to improve environmental performance of Khaya lumber from Ghana in its use as construction material using Life Cycle Assessment (LCA) in accordance with ISO 14040/44. The main goal of the study is to analyze the cradle-to-gate environmental performance of Khaya lumber produced from Ghana and provide credible scientific evidence for informed decision making in areas related to its potential environmental impact with the view to enhance its competiveness on the market.

Therefore the specific objectives of the study are to:

- Compile all the measurable inputs and outputs of the manufacturing process of Ghana Khaya lumber.
- Compile and evaluate all potential impacts to the environment.
- Assess the carbon footprint for Ghana Khaya lumber in line with the PAS2050 methodology.
- Provide an Environmental Product Declaration (EPD) for Ghana Khaya lumber

The study intends to be the basis for EPD of Ghana Khaya lumber. An EPD will provide relevant, verified and comparable information about the potential environment impact of Khaya lumber. The development of EPD in this study will follow Life Cycle Assessment (LCA) (ISO 140 44, 2006).

3.2 Scope of the Study

The following section describes the general scope of the project that has been set to achieve the stated goals. This includes the identification of specific products to be assessed, the supporting product systems, and the boundary of the study.

3.3 System Description

This study is carried out in accordance with ISO-14044, 2006 that specifies requirements and guidelines for conducting LCA. In this study, the system boundary is set for cradle-to-gate assessment because the use phase and end of life phase cannot be relevantly expressed (Gan and Massijaya, 2014).

Figure 2 provides the process flow and system boundaries of the study. It represents the linkages and their unit-processes that together make up the product system or life cycle of the product.

Three basic generic process steps make up the cycle phase of this product. They are:

a) The manufacturing phase:

The manufacturing phase is covered by three steps. Step one includes the harvest of the khaya trees, cross-cutting them into logs, extracting the logs to a dump site in the forest and transporting the logs to the sawmill (factory). Step two is the manufacturing of the product (khaya lumber) in the sawmill. Step three is the transport of the khaya lumber to the producer´s storage prior to kiln drying and thereafter bundling or packaging for export shipping. The storage facilities are sheds within the company's manufacturing premises. The greatest account for resource, energy, waste and good inflows, outflows and activities are in the product's life cycle manufacturing phase. The extraction of the resource and raw material production (timber) are the most environmentally consuming from the generic process steps. The usage phase and the end of life are not included to the quantified part of Khaya lumber product life cycle assessment because it cannot be relevantly expressed due to the varied nature of end use product and disposal of khaya lumber.

b) Use phase

The usage phase of a product normally includes unit processes such as transfer to customers, further processing of the product and duration of product. Transfer of product i.e. Khaya lumber to customers (export and local) and realization of construction cannot be relevantly expressed due to the changeability of unit processes. Duration of product unit process represents operations which are necessary for its preservation in the course of not decreasing qualities of basic parameters and material durability. The durability depends on material quality and production techniques, the techniques laid to installation and climatic effects. The total durability (until the necessary dismantling of product) cannot be relevantly expressed.

c) End of life (dismantling / disposal) phase:

The end of life of wood product is very difficult to relevantly express. Most of such studies are based on assumptions. In conformity with IBU (2009) – Building Products, the end of life assessment of the study product is included in its Environmental Product Declaration (EPD).

LCA may be conducted for cradle-to-grave, cradle-to-gate or gate-to-gate. The cradle -to-grave assessment of khaya lumber covers the timber harvest, extraction, processing to lumber, transportation/delivery, use phase as described in (b) and the end of life dismantling/disposal. For a primary product like khaya lumber, the use phase and final product disposal phase are not fixed and therefore excluded from the quantified part of its LCA limiting it from cradle-to-gate as depicted in Fig.2.

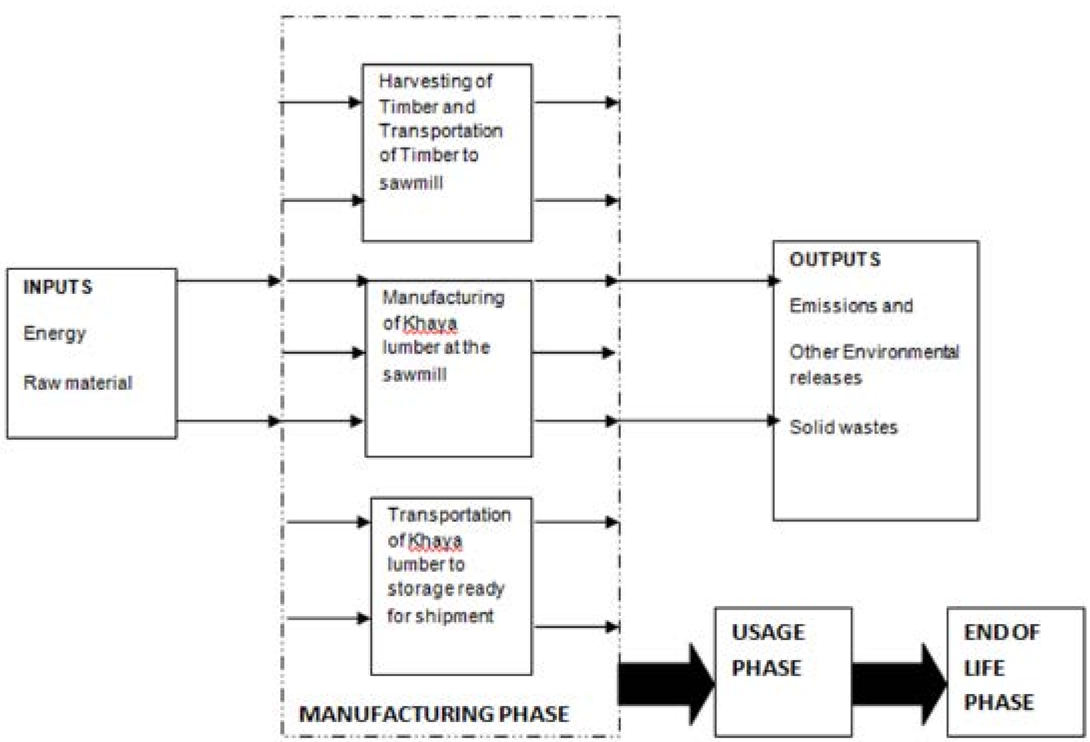

Fig. 2: Cradle to Gate System Boundary of the Life Cycle Assessment Study – inclusions and exclusions

3.4 Manufacturing process of Khaya lumber

Fig.3:Skidder extracting a log in the Forest Fig. 4: Stacker for loading Logs (Fuel used is diesel)

3.4.1 Forestry

The manufacturing phase of the study includes the under listed processes:

- Felling of trees
- Skidding trees to landing sites
- Processing trees into logs
- Loading logs on truck
- Transportation of log to Sawmill

Natural tropical forest is the main source of Khaya timber supply to the timber industry in Ghana. Forest management is labour intensive and no environmental burden isgenerated. The Khaya species in Ghana's tropical forest are harvested by the use of chainsaws whiles bulldozers , tractors and skidders are used for skidding (Fig. 3), then the logs are cross-cut with chainsaws and loaded with stackers (Fig. 4) onto articulated trucks to be delivered to the sawmill . Some biomass (limbs, tops and other non-merchantable materials also known as slash) are left in the forest. In Ghana no slash reduction activities are carried out for fire risk reduction; the slash decay in situ. The main valuable product of the forest processes is timber logs.

3.4.2. Sawmilling

- Log yard
- Sorting and storage of logs
- Debarking of logs
- Bucking of logs
- In-yard transportation

- Breakdown of logs into rough-sawn lumber
- Trimming, grading and sorting
- In the sawing process, Khaya logs are sawn into rough-sawn green Khaya lumber (mostly 25 mm, 32mm, 38mm and 50 mm thick, random widths and mostly 2.44-3.66 m lengths (Fig.5 & 6). Rough sawn Khaya lumber is not planed. The outputs of this process are green rough sawn Khaya lumber and wood residues from the sawing process: bark, sawdust and off cuts (slabs, edgings, and chips). Most wood residues are combusted as fuel for steam generation, mostly to dry lumber.

Fig 5 & 6: Sawmill Bandmill - Break logs to slabs (Energy used is electricity)

3.4.3. Drying of Lumber

- Pre-dryer (Optional)
- Air drying (Optional)
- Kiln drying
- Internal Transportation

This unit process begins with rough-sawn green Khaya lumber and includes: pre-dryer (sometimes); air drying yards (not with khaya); drying, equalizing, and conditioning of lumber in a kiln.; internal transportation. Khaya lumber rarely goes through pre-drying or air-drying. The output of this process is rough sawn, kiln dried lumber. All of khaya lumber is dried in mostly steam heated (Fig. 9) kiln driers (Fig. 7) before export. This is not necessarily so for khaya lumber sold locally. Different drying methods and schedules are used in kiln drying processes and energy consumption

varies widely depending on species, lumber thickness and grade, and

Fig. 7: Kiln Dryer (Energy used are electricity to run the fans + steam to heat the chambers)

the adopted drying schedule. The kiln drying process for khaya is modeled to reflect these specific features. The daily energy consumption of a kiln is modeled based on the equipment efficiency and size of timber being dried. The number of days the timber is dried inside the kiln is then adjusted depending on the species, thickness of lumber product and amount of moisture needed to be removed from the wood (the moisture content of input lumber and moisture content required for kiln-dried lumber as per the contract terms).

3.4.4 Transport

Transportation was modeled taking into account the transportation mode (use of articulated trucks, Fig.8) and the fuel consumption . Primary data on transportation mode and fuel consumption was obtained from companies visited. Transport methods modeled include transportation of the logs from the forest to saw mill, transportation of green khaya lumber from saw mill to kiln, transportation of the dried lumber to the company's warehouse ready for export. This study did not consider the transport of khaya lumber to the port and hence export overseas to its final port in Europe. The onward transportation of lumber to customers in Europe and local destination was excluded because it cannot be relevantly expressed due to the changeability of unit processes.

Fig 8: Trucking of Logs from Forest to Factory (Fuel used is diesel)

3.4.5 Company's Warehouse

This included a transportation activity which involved moving finished goods to be warehoused prior to sales.

3.5 Function

Khaya Lumber is an intermediate product which can be processed further into final products to be used for a wide range of applications including, furniture and cabinets to internal joinery such as doors, stairs, floorings and paneling.

3.5.1 Functional unit

A functional unit of the study 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 (AHEC, 2009). Therefore the functional unit of rough sawn khaya lumber product produced at specific moisture content and thickness to be used by this study is $1m^3$ (one cubic meter)of 25 - 50 mm thickness at 12% Moisture content. The functional unit (FU) quantifies performance/function of a product system for use as a reference unit. The functional unit chosen is consistent with the Product Category Rules (PCR) for solid wood products.

3.6 Life Cycle Iinventory (LCI)

The compilation of a comprehensive life cycle inventory (LCI) database is to identify the most dominant potential environmental impacts for the production of a product, reference Eshun et al (2010). LCI value is very important in product evaluation. Most studies focus on the uncertainty of data in Life Cycle Assessment (LCA) tools database. However, the accuracy and quality of inventory process in LCA analysis is also very important for the results of computing LCA. Furthermore, different softwares have the same data name but the impact assessment results of data are not the same. Therefore, there is a need to develop a selection process for choosing best suitable data for the LCA calculation. Emission inventory data are not available for the timber companies in Ghana. We have to use emission factors from standard reference(s) to calculate selected emissions as function of production volumes of Khaya lumber according to equation 1. This will make the resulting emissions as local as possible.

All raw materials and emissions (inputs and outputs) are considered for each of the processes that make up the life cycle of the product. Inputs include the use of resources, such as timber and water, as well as material inputs, such as fuels, etc. The khaya wood is not chemically treated in storage because it is not stored for long periods before sawing while the lumber produced after sawing is mostly out of the heartwood which isquite durable and resistant to impregnation if it were to be treated. Outputs are the emissions into air, water and land, as well as all products and by-products. Taken together these processes make up the life cycle system to be analyzed, as defined by the system boundary. The individual inputs and outputs from all processes making up the system will be summed together to compile the life cycle inventory (LCI) – a list of all raw materials entering the system and final emissions leaving the system, given per relevant unit of product produced per year.

The LCI forms the basis of life cycle impact assessment (LCIA). In the next phase of LCA, all the inputs and outputs are grouped into environmental impacts or areas of environmental concern, for example, climate change, acidification, eutrophication, smog and human toxicity.

LCA is by its very nature data intensive. It is common to use a mixture of primary (site or factory-specific) data and secondary data (LCI databases). The greater the contribution of the former, the more expensive and time-consuming the study is, but the more representative the results.

This study will consider accounting emissions contributing to global warming, acidification, eutrophication, smog, and human toxicity. The emissions to be considered areCarbon dioxide CO_2, Methane CH_4, and Nitrous oxide N_2O for global warming; Sulphur dioxide SO_2 and Oxides of Nitrogen NO_X for acidification; Nitrogen Oxides (NOx) for eutrophication; CH_4, NO_X, Non-Methane volatile organic compound NMVOC, Carbon monoxide CO for smog; NO_X and SO_2 for human toxicity. The study did not consider emissions contributing to Ozone Depletion Potential (ODP) due to lack of data availability. The result of emission calculations is expressed in equations 1 & 2 in kilograms per cubic meters of pollutant either emitted or generated from a product line of khaya lumber.

Emission = Activity x Emission Factor_____________________________________Equation 1

Impact category indicator = Emission (inventory data) x Classification Factor____Equation 2

Table 1: Emission factors for the calculation of the emissions from Khaya lumber production in Ghana

Activity area	Compound emitted	Emission factors	Unit	Reference
Forestry subsystem				
Harvesting activities	CO_2	3172.00	g / kg fuel	CORINAIR (2000)
(Gasolinel used)	CO	14.07	g / kg fuel	CORINAIR (2000)
	N_2O	0.02	g / kg fuel	CORINAIR (2000)
	CH_4	7.67	g / kg fuel	CORINAIR (2000)
	NO_X	1.55	g / kg fuel	CORINAIR (2000)
	NMVOC	762.00	g / kg fuel	CORINAIR (2000)
	SO_2	0.07	g / kg fuel	CORINAIR (2000)
Harvesting activities	CO_2	3150.00	g / kg fuel	Schwaiger and Zimmer(1995)Jawjit, W. (2006),
(Diesel used)	N_2O	0.02	g / kg fuel	
	CH_4	6.91	g / kg fuel	Schwaiger and Zimmer(1995)Jawjit, W. (2006),
	NO_X	50.00	g / kg fuel	
	NMVOC	6.50	g / kg fuel	Schwaiger and ZimmerJawjit, W. (2006),
	CO	15.00	g / kg fuel	IPCC (1997)
				IPCC (1997)
	SO_2	20.00	g / kg fuel	IPCC (1997)
				IPCC (1997)
Transportation of log to company(Diesel used) +mk	CO_2	3180.00	g / kg fuel	Schwaiger and Zimmer(1995)Jawjit, W. (2006),
	N_2O	0.10	g / kg fuel	
(Sawmill operations and internal transport Diesel used)	CH_4	0.20	g / kg fuel	Schwaiger and Zimmer(1995)Jawjit, W. (2006),
	NO_X	29.80	g / kg fuel	
	NMVOC	4.70	g / kg fuel	Schwaiger and Zimmer(1995)Jawjit, W.

	CO	14.00	g / kg fuel	(2006),
	SO_2	20.00	g / kg fuel	IPCC (1997)
				IPCC (1997)
				IPCC (1997)
				IPCC (1997)
Electricity use	CO_2	77.40	ton/TJ	IPCC (2010)
Fossil-fuel/Thermal energy	CH_4	2.00	Kg/TJ	IPCC (2010)
	N_2O	0.60	Kg/TJ	IPCC (2010)
	NMVOC	5.00	Kg/TJ	IPCC (2010)
	CO	10.00	Kg/TJ	IPCC (2010)
	NO_X	200.00	Kg/TJ	IPCC(2010)
	SO_2	1194	Kg/TJ	IPCC(2010)

3.7 Selection of Impact Assessment Categories

3.7.1 Assessment of possible approaches/methodologies

A comprehensive set of environmental impact categories were investigated (Table 2). The literature reviewed showed that the LCIA approaches in the reviewed LCAs are indeed shown 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 (Eshun et al. 2011). Most life cycle impact assessment (LCIA) approaches in life cycle assessment (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 Ghana. LCA study on the timber product does not only involve foreground data on timber and the manufacturing processes, but also other local inputs and outputs (background data) to holistically represent the whole product system or life cycle. Table 2 shows the evaluation of LCIA methods and characterization factors in LCA studies.

Table 2 Evaluation of LCIA methods and characterization factors in LCA studies

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)
Global warming	kg CO_2 eq	kg CO_2 eq	kgCO_2	DALY
Ozone layer depletion	kg CFC 11 eq	kg CFC 11eq	kg CFC 11	DALY
Acidification	kg SO_2 eq	kg SO_2 eq	kg SO_2	PAF*m^2yr

	mole of H^+ eq			
Eutrophication	kgNO_3 eq	kg PO_4 eq	kg PO_4	PAF*m^2yr
Photochemical oxidant	kg C_2H_4 eq	kg C_2H_2 eq	kg C_2H_4	kg C_2H_4
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

Characterization methodologies for different impact categories may not be necessarily relevant to African tropical environmental conditions (Eshun et al. 2011).Review of LCIA approaches and characterization methods show 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 use the CML-2000 approach for this environmental impact assessment.

Table 2 evaluatesthe scientifically well-recognized CML 2000 methodology to Life Cycle Inventory (LCI) results and selects the impact categories to apply as global warming, acidification, eutrophication, photochemical oxidant formation and human toxicity and with their description outline in Table 3 and Table 4.

Table 3: Selected impact categories, LCIA method and characterization factors used in the LCA study in 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_2eq 1kg = 21 CO_2eq 1kg = 310 CO_2 eq	Converts LCI data to carbon dioxide (CO_2) equivalents Note: global warming	(IPCC, 2006) (Houghton et al. 1996)

				potentials for 100 year potentials.	
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-methanehydrocarbon (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),Goedkoop (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)

Table 4: Life cycle impact assessment categories & indicators

Category Indicator	**Impact Category**	**Description**	**Unit**	**Reference**
Climate Change	Global Warming Potential (GWP)	A measure of greenhouse gas emissions, such as $CO_2$and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, magnifying the natural greenhouse effect	kg CO_2 equivalent	IPCC, 2006, 100 year GWP is used
Acidification	Acidification Potential (CML)	A measure of emissions that cause acidifying effects to the environment. The acidification potential is assigned by relating the existing S-, N-, and halogen atoms to the molecular weight	kg SO_2 equivalent	Guinée et al., 2001, factors updated in 2010
	Acidification Potential (TRACI)		kg H+ equivalent	
Eutrophication	Eutrophication Potential CML	A measure of emissions that cause eutrophying effects to the environment. The eutrophication potential is a stoichiometric procedure, which identifies the equivalence between N and P for both terrestrial and aquatic systems	kg Phosphate equivalent	Guinée et al., 2001, factors updated in 2010
Ozone creation in troposphere	Photochemical Ozone Creation Potential (POCP)	A measure of emissions of precursors that contribute to low level smog, produced by the reaction of nitrogen oxides and VOC's under the influence of UV light	kg Ethene equivalent	Guinée et al., 2001, factors updated in 2010
Human toxicity	Human toxicity Potential	A measure of emissions that cause human toxicity effects to the	Dichlorobenzene equivalent	CML 2000

3.7.1.1 Global warming

Greenhouse gases, which are the main pollutants contributing to global Warming problem, are expressed as Global Warming Potentials (GWP). The GWP is an index of cumulative radiative forcing between the present and some chosen later time horizon caused by a unit mass of gas emitted, expressed relative to the reference gas CO_2(1 kg CO_2) (Houghton,1994). The combustion of fuels for Khaya lumber production is the major source of these gases.

Fig. 9: Furnace; burning wood to produce steam for heating kiln dryers

3.7.1.2 Acidification

The processes of Khaya lumber production generates acidifying agents. The combustion of fuel in khaya production is the main source of NO_x emission. Acidification is measured as the amount of protons released into the terrestrial/aquatic system. The classification factors of acidification potential (AP) are routinely presented either as moles of H^+ or as kilograms of SO_2 equivalent (Heijungs ., 1992). The latter is used in this study.

3.7.1.3 Eutrophication

Enrichment of the water and soil with these pollutants (Nitrogen Oxides (NOx))may cause an undesirable shift in the composition of species within the ecosystems, a process called eutrophication. Several models have been proposed to characterize the contribution from life-cycle inventory data to eutrophication. One well-known model has been proposed by Heijungs et al. (1992); this model calculates the nutrification potential (NP) of emissions in relation to the one from the reference compound PO_4^{3-}

3.7.1.4 Smog

The combustion of fuel during khaya production process and transportation of khaya timber causes the emission of VOCs, CO, CH_4 and NO_x, which are considered to be tropospheric ozone precursors. Photochemical Ozone Creation Potentials (POCPs) have been developed to aid in the assessment of the relative contribution of different organic compounds to tropospheric ozone formation. The value of classification factor of POCPs is taken from Goedkoop (2000) (PReConsultants, Amersfort, the Netherlands) who developed the Eco-indicator 95.

3.7.1.5 Human toxicity

In the timber industry, one of the important pollutants is the emissions of particulates, SO_2, and NO_x which contribute to human toxicity problem. Classification factors in this environmental theme are taken from CML (2002).

3.8 Database development and carbon footprint assessment for khaya lumber

Carbon footprint is a more recent term for global warming potential and refers to the total greenhouse gas emissions associated with a product or service. Emissions of different individual greenhouses gases are converted into global warming potential and expressed in the common unit of CO_2 -equivalents.

Carbon footprint is a term used to describe the amount of greenhouse gas (GHG) emissions caused by a particular activity or entity, and thus a way for companies to assess their contribution to climate change. It includes the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Understanding these emissions, and where they come from, is necessary in order to reduce them. In the past, companies wanting to measure their carbon footprints have focused on their own emissions, but now they are increasingly concerned with emissions across their entire supply chain.

The carbon footprint is an environmental indicator that measures the impact of human activities on global climate and expresses quantitatively the effects produced by so called greenhouse gases in terms of carbon dioxide equivalent (CO_2 - eq). To develop the carbon footprint database for Khaya lumber production, all the direct emissions associated with Khaya lumber production are measured and assessed from the LCA studies.

Two types of data are necessary to calculate a carbon footprint: activity data and emission factors. Activity data refers to all the material and energy amounts involved in the product's life cycle (material inputs and outputs, energy used, transport, etc.) – Emission factors provide the link that converts these quantities into the resulting GHG emissions: the amount of greenhouse gases emitted per 'unit' of activity data (e.g. kg GHGs per kg input or per kWh energy used). Activity data and emissions factors can come from either primary or secondary sources.

- Primary data refers to direct measurements made internally or by someone else in the supply chain about the specific product's life cycle.

- Secondary data refers to external measurements that are not specific to the product, but rather represent an average or general measurement of similar processes or materials (e.g. industry reports or aggregated data from a trade association.

The equation for product carbon foot printing is the sum of all materials, energy and waste across all activities in a product's life cycle multiplied by their emission factors. The calculation itself simply involves multiplying the activity data by the appropriate emission factors.

It is calculated by multiplying the emissions of each greenhouse gas for its warming potential (GWP) according to equation 1. LCI data will be converted to carbon dioxide (CO_2) equivalents at global warming potentials for 100 according to equation 2.

PAS 2050 (2008) takes a process life cycle assessment (LCA) approach to evaluating the GHG emissions associated with goods or services, enabling companies to identify ways to minimize emissions across the entire product system. PAS 2050 (2008) guide explains how to assess GHG emissions of an individual product, either a good or a service, across its entire life cycle – from raw materials through all stages of production (or service provision), distribution, use and disposal/recycling. It is an independent standard, publicly available specification , developed with significant input from international stakeholders and experts across academia, business, government and non-governmental organisations (NGOs) through two formal consultations and multiple technical working groups. The assessment method has been tested with companies across a diverse set of product types, covering a wide range of sectors including:

- Goods and services
- Manufacturers, retailers and traders
- Business-to-business (B2B) and business-to consumer (B2C)

PAS 2050 can deliver the following benefits: For companies, it can provide:

- Internal assessment of product life cycle GHG emissions
- Evaluation of alternative product configurations, operational and sourcing options, etc. on the basis of their impact on product GHG emissions
- A benchmark for measuring and communicating emission reductions
- Support for comparison of product GHG emissions using a common, recognised and standardised approach
- Support for corporate responsibility reporting

All data used in a PAS 2050 (2008) -compliant carbon footprint assessment must meet the Data Quality Rules. This assures accurate, reproducible and more readily comparable carbon footprints. Good quality data helps to build a footprint that represents a ‘typical’ product’s life cycle over a defined time period, recognizing variations in geography, distance and materials.

3.9 Assessment of carbon footprint and LCA development for Khaya lumber EPD

The term ‘product carbon footprint’ refers to the GHG emissions of a product across its life cycle, from raw materials through production (or service provision), distribution, consumer use and disposal/ recycling.

Several ISO standards relate to the assessment of a carbon footprint at different systems’ levels. This study uses LCA methodology in accordance with ISO-14044 (2006) to assess the carbon footprint of khaya lumber manufacturing from Ghana.

4.0 Field study

4.1 Company survey

Company sizes in Ghana are categorized by their log input. The log inputs in m^3 of the companies are used to identify them as large, medium and small. Annual round log input in all species of timber for large size companies is 25,000 m^3 and above; medium size is 15,000 m^3 but less than 25,000; small size is less than 15,000 m^3. Questionnaires were administered to three (3) selected timber companies (for purposes of this study named companies A, B, C) all fromthe large size category to provide data about the inputs and outputs of their activities for resources, material uses, energy requirements, and waste production for the year 2013. The terms of reference (TOR) of the study required data sets from three (3) factories. The random selection of the three companies ensured data availability and their reliability. Additional interview was done to check data quality in reasonably appropriate form to assist the LCAprocess. The companies produced khaya kiln dried lumber and the factories are located about 50, 130 and 250km respectively for A, B, C from log sources. In addition to lumber, company A produces sliced & rotary veneer and plywood; company B sliced veneer and moldings and company C sliced veneer, moldings and square edged lumber. Electricity source for the companies is the national grid and the energy mix in Ghana is 50% hydropower and 50% thermal power. Hydropower is considered green energy and therefore the environmental burden was considered negligible and only the thermal energy was considered in this study.

Exports of air-dry mahogany lumber from Ghana attract a levy and therefore 98.6% (5,843m^3) of African mahogany exported in 2012 (with available annual data) was kiln dried. The predominant khaya species is the ivorensis. Export lumber is dried from green to 10-12% moisture content based on US schedule 56(T6-D4) for thicknesses 25, 32, 38mm and schedule 20(T3-D3) for thickness 50mm both of which correspond to British schedule F. It takes 14 days to dry 25mm thick lumber and 20 days to dry the 50mm thick lumber. Companies A, B, C are large size and among the few that keep data in reasonably appropriate form to assist the LCA process. Each company undertakes own logging from the forest and trucks the logs to their factories to process.

4.2 Data quality and representativeness

The study is based on the primary data (Tables 5 and 6) obtained from company survey in Ghana and literature values (Table 3). Literature based values from IPCC 2006 were confirmed with primary data. Based on key quality criteria discussed below, the overall quality is estimated as very good. The data quality is concluded to be the best available data and is sufficient for the defined goal and scope.

4.3 Allocation

The companies were selected to cover one product line (lumber), namely, kiln dried khaya lumber and therefore the level of process detail was sufficient to avoid multiple output processes.Percentages were apportioned for khaya production from the total sawmills production (other lumber Species) based on mass (density x volume) allocation.

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5.0 Results and Discussions

5.1 Life Cycle Inventory (LCI) Analysis

The three companies provided data about their material uses and energy requirements for their operations in 2013. The collected data were first converted into total annual average values (Tables 5 and 6), and then expressed per functional unit on the basis of their production outputs in volume (Table 7). Emissions for the several activities were taken from literature.

Table 5 Activity data from the year 2013 survey for the calculation of khaya lumber produced in Ghana used for modeling cradle-to-gate of Khaya lumber produced in Ghana

Log Input	Company A m^3/year	Company B m^3/year	Company C m^3/year	Average m^3/year
KhayaRound log input, (hardwood, green)	13,014	2,463	2,030	5,836
Log Output:				
Sawn lumber, hardwood, rough, green	5,324	1215	1133	2557
Sawn lumber, hardwood, rough, Kiln dried	5,324	1215	1133	2557

Table 6: Activity data from the year 2013 survey for the calculation of emission from khaya lumber produced in Ghana used for modeling cradle-to-gate of Khaya lumber produced in Ghana

Source	Activity	Company A	Company B	Company C		
		Value	Value	Value	Average	Unit
Khaya logs harvested	Diesel use	130,771	24,749	20,398	58,639	Kg fuel/year
	Gasoline use	7,639	1,444	1,192	3,425	Kg fuel/year
Khaya logs transportation to sawmill	Diesel use	103,933	19,643	16,214	46,597	Kg fuel/year
Sawmill operations	Diesel use	28,919	5,466	4,511	12965	Kg fuel/year
Sawmill internal transportation	Diesel use	10,611	2005	1,655	4757	Kg fuel/year
Electricity use	Thermal power energy	10.5	1.5	1.0	4.35	TJ/year

Density of diesel 832kg/m^3at 15^{o}C Density of gasoline745kg/m^3 at 15^{o}C

Table 7. Activity data for the calculation of emission from khaya lumber produced per cubic meter in Ghana used for modeling cradle-to-gate of Khaya lumber produced in Ghana

Source	Activity	Company A	Company B	Company C	Average	Unit
Khaya logs harvested	Diesel use	24.56254696	20.36954733	18.00353045	20.97854158	Kg fuel/m^3
	Gasoline use	1.434823441	1.188477366	1.052074139	1.225124982	Kg fuel/m^3
Khaya logs transportation to sawmill	Diesel use	19.5216003	16.16707819	14.31067961	16.6664527	Kg fuel/m^3
Sawmill operations	Diesel use	5.431818182	4.498765432	3.981465137	4.637349584	Kg fuel/m^3
Sawmill internal transportation	Diesel use	1.993050338	1.650205761	1.460723742	1.701326614	Kg fuel/m^3
Electricity use	Thermal power energy	0.001972202	0.001234568	0.0008826125	0.001363128	TJ/m^3

5.2 Application of the selected LCIA approach for LCA study

This section applies CML 2000 to the LCI results of the survey for characterization of the impact categories of Global Warming, Acidification, Eutrophication, Photochemical Oxidant Formation, and Human Toxicity. Table 4 provides the CML-2000 characterization factors used for these impact categories. Excerpt for acidification, an alternative generic acidification potential was used which seeks to adequately quantify the acidifying potential in an African situation, than that in CML-2000 which is site specific and a European baseline approach (Hauschild and Potting, 2005). Characterization of Biodiversity for the timber sector is now being developed and for that matter was not considered in this study. Fig. 10 depicts the overall LCIA results while Table 9 is a summary of potential impacts for the production of 1 m^3 of kiln dried khaya lumber as pertained in 3 Ghanaian companies. Individual impact categories are analyzed in 5.2.1 - 5.2.6.

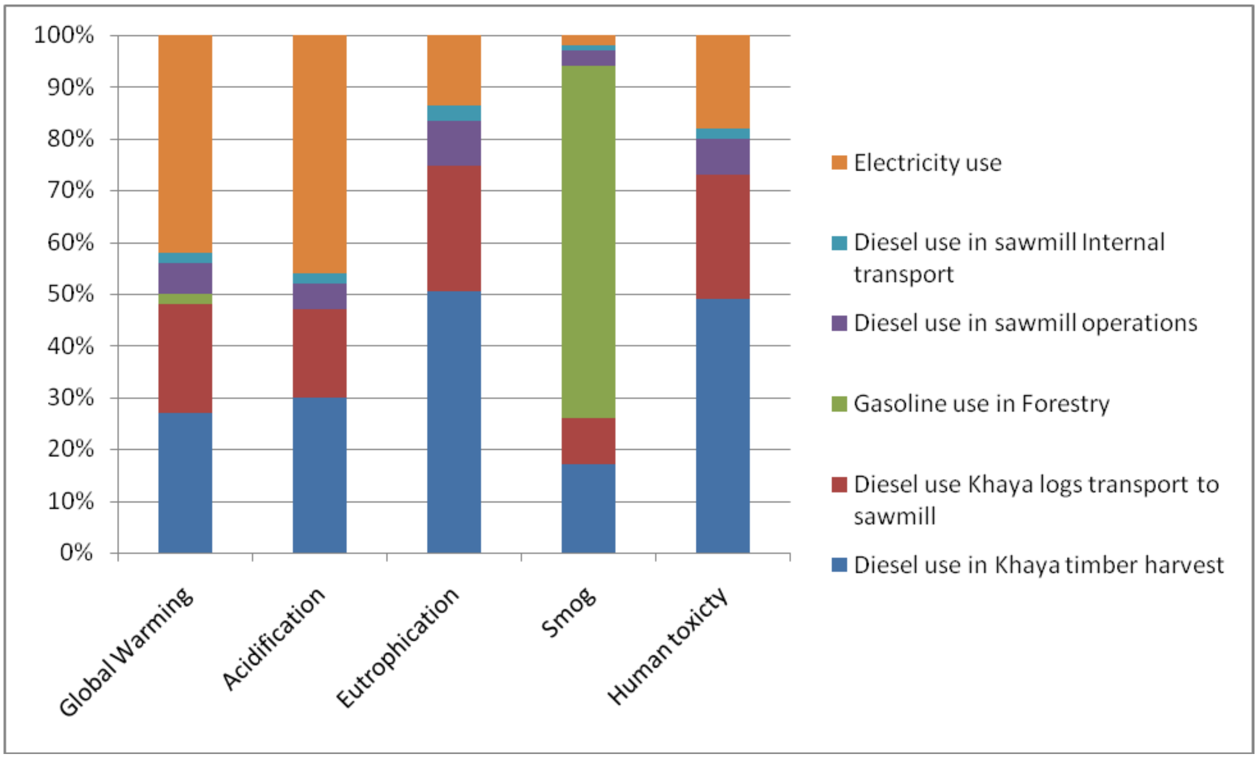

Figure 10: Relative contribution by different activities to the total potential environmental impact per cubic meter of Khaya lumber production in Ghana

5.2.1 Global Warming Potential (GWP)

An average of 253 kg CO_2-equivatents of greenhouse gas is emitted per cubic meter in kiln dried Khaya lumber production in Ghana as shown in Table 8. When we considered the activities that generate greenhouse gases, electricity (component of thermal generated electricity) use ranks the first, with the share of 42%. The second contributor belongs to diesel use in khaya timber harvest; with a relative impact of 27% followed by diesel use in khaya timber transport to sawmill of 21%. Based on these data, it is clear that the global warming potential (GWP) is strongly related to the use of fossil fuel (diesel use) as seen in Figure 10. Electricity use by thermal generation, khaya timber harvesting activities and the transport of logs over long distances from forest to processing factories, the rough nature of roads and the poor condition of haulage trucks in Ghana (due to lack or inadequate maintenance) accounted for the high diesel use recorded in the study. The best environmental intervention to reduce high diesel use is the use of green energy technology such as solar, wind and hydropower in Ghana in lumber production, while re-locating factories close to forest source of timber or transporting the timber by rail.

Table 8 Potential environmental impacts from Khaya lumber production per one cubic meter in Ghana.

Activity/Source	Company	GWP	AP	EP	POCP	HT
		Kg/m^3 CO_2-eq x10^{-3}	kg/m^3 SO_2-eq x10^{-3}	kg/m^3 PO_4-eq x10^{-3}	kg/m^3 C_2H_2-eq x10^{-3}	kg/m_3 $C_6H_4Cl_2$=eq x10^{-3}
Diesel use Harvesting	A	81088.4253	1363.2187	1596.5625	111.7688	1520.91
	B	67246.033	1130.5072	1324.0175	92.6896	1261.279
	C	59435.1345	999.1942	1170.2275	81.9228	1114.776
	Av	69256.5311	1164.3067	1363.6025	95.4598	1298.988
Diesel use Transport to sawmill	A	62765.8483	803.4699	756.2666	61.8585	735.5734
	B	51980.1384	665.4013	626.309	51.2285	609.1719
	C	46011.4411	588.9956	554.3925	45.3465	539.2229
	Av	53585.8093	685.9556	645.6563	52.8117	627.989
Gasoline use in Forestry	A	4791.1827	1.6794	2.8911	455.493	2.6782
	B	3968.3884	1.39098	2.3946	377.27	2.21838
	C	3512.9237	1.23144	2.1199	333.99	1.96386
	Av	4090.9396	1.4339	2.4674	388.914	2.2868
Diesel use sawmill operations	A	17464.3555	223.5624	210.428	17.211	204.6704
	B	14464.219	185.16	174.282	14.253	169.5133
	C	12801.3096	163.8689	154.24	12.6156	150.021
	Av	14909.847	190.8636	179.65	14.694	174.734
Diesel use internal transport	A	6408.0528	82.0299	77.2106	6.3152	75.0979
	B	5305.72304	67.9189	63.9286	5.2286	62.1794
	C	4690.9854	60.1203	56.588	4.6284	55.0398
	Av	5470.084	70.023	65.90129	5.3909	64.1056
Electricity use	A	153081.614	2636	512.72	15.655	699.2
	B	95831.466	1649.19	320.97	9.807	437.77
	C	68983.465	1179.01	229.4	6.9832	312.91

	Av	105800.764	1820.9	354.3	10.814	483.4
Total	A	325599.4786	5109.9603	3156.0788	668.3015	3238.1299
	B	238795.9678	3699.56838	2511.9017	550.4767	2542.13198
	C	195435.2593	2992.42044	2166.9679	487.6283	2173.93356
	Av	253113.975	3933.4828	2611.5775	568.0844	2651.5034

5.2.2 Acidification Potential (AP)

The average potential acidification impact from khaya lumber production from Ghana is 3.9kg SO_2-eq per cubic meter as shown in Table 8. When contributors of total acidifying emission were considered, it was found that Diesel use in electricity generation contributed 46% to the total emission, which is the largest proportion followed by diesel use in khaya timber harvesting (30%) as depicted in Fig. 10 .

5.2.3 Eutrophication Potential (EP)

The average eutrophying impact amounted to 2.6Kg PO_4-eq per a cubic meter, shown in Table 8. Among pollutants of eutrophying compounds NO_X emitted during Khaya timber harvesting activities from diesel use contributed 52%, followed by diesel use in khaya timber transportation to sawmill (24%) as shown in Fig. 10.

5.2.4 Photochemical Ozone Creation Potential (POCP)

From Table 8, the potential impact of tropospheric ozone precursor compounds is 0.56kg ethylene-eq per cubic meter. There were two major important sources with respect to contributors to the smog problem: gasoline use in khaya timber harvest and diesel use in khaya timber harvesting activities. Gasoline use in khaya timber harvesting ranked the first with a share of almost 68%. The second contributor belonged to diesel use in khaya timber harvesting activities with relative emission of 17%. The details are provided in Fig. 10.

5.2.5 Human toxicity (HT)

The potential human toxicity impact is 2.6Kg $C_6H_4Cl_2$ –eq per a cubic meter as in Table 8. The major source of human toxicity compounds was the diesel used in khaya timber harvesting activities constituting 49% followed by diesel used in khaya transportation to sawmill (24%), shown in Fig. 10.

5.3 Assessment of the carbon footprint for Ghanaian Khaya lumber in line with the PAS2050 methodology

Carbon footprint is a more recent term for global warming potential and refers to the total greenhouse gas emissions associated with a product or service. Emissions of different individual greenhouses gases are converted into global warming potential and expressed in the common unit of CO_2 –equivalents. The CO_2 emission for determining the carbon footprint of product may be obtained from a full LCA study. Therefore, considering Table 8 the average GWP of 253 kg CO_2-Equiv. may be taken as the carbon footprint for one cubic meter of khaya lumber produced from Ghana.

5.4 Environmental Product Declaration (EPD) for Ghana Khaya lumber

Environmental product declarations are standardized documents used to communicate the environmental performance of a particular product based on LCA. According to Table 9, the average environmental impact for khaya lumber produced in Ghana per cubic meter in term of GWP was 253 kg-CO_2-Eq , AP was 3.9kg SO_2- Eq, EP was 2.6 kg Phosphate (PO_4)-Eq, POCP was 0.56kg Ethylene-Eq and HP was 2.6Kg $C_6H_4Cl_2$ – Eq.From this result the GWP, AP, EP and POCP compare favorably with the Life Cycle Impact Assessment (LCIA) results for 1m^3 rough-sawn, kiln dried US lumber cradle to gate for 19 different species as well as the LCA results for environmental product declaration of tropical plywood production in Malaysia and Indonesia (AHEC. 2009, Gan and Massijaya. 2014).

Table 9: Summary of potential environmental impact for the production of a unit (1 m^3) of kiln dried khaya lumber

Company	GWP kgCO_2 - Equiv	AP kgSO_2 - Equiv	EP kgPO_4 - Equiv	POCP kgethylene - Equiv	HTP kg$C_6H_4Cl_2$ - Equiv
A	325.60	5.10	3.16	0.67	3.24
B	238.80	3.70	2.51	0.55	2.54
C	195.44	2.99	2.17	0.49	2.17
Average	253.11	3.93	2.61	0.57	2.65

Considering all the potential environmental indicators outlined in this LCA study of khaya lumber produced from Ghana, it could be declared that khaya lumber product which is managed from a sustainable tropical natural forest performs well environmentally in Ghana.

6.0 Limitations, Conclusions and Recommendations

6.1 Limitations

Time and budget was a major constraint to this study. However, the results of this assessment are to be used according to the defined goal and scope of this study.The omission of certain life cycle impact categories may result in an incomplete picture of the overall performance of the studied products. For example Biodiversity and Ozone Depletion Potential were not covered in the LCA studies due to the lack of mature and consistent methodology especially in Africa and specifically in Ghana. Biodiversity and Ozone Depletion Potential and Biodiversity impacts of hardwood production should be revisited in the future as new and reliable methodologies become available. The classification factors used, such as global warming potentials (GWPs), acidifying and eutrophying potentials are also subject to uncertainties because these values were not developed in Ghana or on Ghanaian-based data, although GWPs are commonly used and accepted as classification factor for greenhouse gases (IPCC, 1997). The classification factors we used for calculating the PO_4-equivalents of eutrophying emissions are less widely used and are based on several assumptions (Heijungs et al., 1992). PO_4-equivalents are generally used in LCA studies to indicate the gross effect of eutrophication irrespective of the location of the emissions. However, eutrophication is an environmental problem with typically local effects, and the eutrophication potentials may change when eutrophication is considered as a local problem.Emissions contributing to OPD were not considered due to lack of available data in Ghana. Despite these limitations the estimated emission and potential environmental impact presented here is the best available at the present and, therefore, they served the purpose of the study.

6.2 Conclusions

Life cycle assessment was used to assess and evaluate the environmental performance of the khaya lumber produced in Ghana. The results of this study indicate that the environmental impact associated with khaya lumber production in Ghana is mainly caused by the use of fossil fuels. A change from using fuels in electricity generation, forest operations and timber transport, to renewable energy sources is an option that holds interesting prospects. The high return of inherent energy in timber compared to energy use in forest management makes timber a very interesting energy carrier (Lindholm and Berg, 2005). Furthermore, to improve the environmental performance of khaya lumber production in Ghana, companies could reduce diesel use by trucks and resorting to improve transportation systems such as rail system and also improve material flow in the manufacturing process to reduce internal transportation. High frequency drying using solar energy is also an excellent environmental improvement for kiln drying of khaya lumber. Wood waste forms a critical issue and requires urgent attention. This may be adjusted for Environmental Product Declaration use based on the selected scheme or Product Category Rules. From this study the results for GWP, AP, EP and POCP compare favorably with the Life Cycle Impact Assessment (LCIA) results for $1m^3$ rough-sawn, kiln dried US lumber cradle to gate for 19 different species as well as the LCA results for environmental product declaration of tropical plywood production in Malaysia and Indonesia (AHEC. 2009, Gan and Massijaya. 2014). Considering all the potential environmental indicators outlined in this LCA study, we therefore conclude that khaya lumber produced from Ghana which is managed from a sustainable tropical natural forest performs well environmentally. All data used in this study to quantify the emissions and potential environmental impact is considered to be the best data available at the present and, therefore, they served the purpose of the study.

This study has yielded good quality primary data unique for LCA research in Africa. This will enhance LCA approaches in Ghana, and allow the identification of the main environmental pressures and their dominantly contributing processes in the timber industry .

6.3 Recommendations

A comprehensive and transparent LCA for the timber industry provides industry it with an overview of areas in which material and thus economic savings can be made for the good of both the environment and industry finances. Improvement in 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.

Based on the study findings it is recommended that:

6.3.1 Governments:

- Provide policy and institutional environment congenial to industrial performance and research in Africa
- Where road transport cannot be substituted, road networks need improvement in order to reduce excessive use of diesel fuel in transporting industrial raw materials on poor roads.
- Invest in railway systems to reduce frequent damage to road network as a result of transportation of heavy equipment and raw materials over long distances in producer member countries. Such rail systems will also enhance bulk carriage in other sectors.
- Invest in the use of green energy technology within countries and across regions in electricity generation such as solar, wind and hydropower to reduce high diesel use.

6.3.2 International Tropical Timber Organization (ITTO)and its members:

- Support further LCA research to promote other tropical hardwood species (especially the more predominant and commonly traded species) and their products in tropical timber producing member countries
- Communicate the environmental information for tropical hardwood lumber (and products) per hardwood species to enable the consumers make informed decisions
- Prepare and publish the EPDs on key tropical hardwood products for information of the public as part of awareness creation and publicity for promoting the use of tropical timber

6.3.3 Member states:

- Create research platform to share ideas on EPDs
- Build capacities in LCA research to enhance sustainability of the timber industry

6.3.4 Private sector:

- Improve on transportation of timber (use of newer models of vehicles, better maintenance of vehicle to minimize environmental impact of timber operations in support and to support development of markets for tropical timber products
- Invest in technology to minimize wood waste in the entire timber production processes which is critical to reduce the concomitant environmental impacts
- Improve on records management systems within companies to provide quality data for LCA studies.

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