Environmental Impact of Lumber Production using Life Cycle Assessment: A Case Study of the Production System in South-west Nigeria

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Abstract—Life Cycle Assessment (LCA) is a decision support tool that can be used to evaluate the potential environmental impact of a product system. Environmental impact associated with the production of (0.0508×0.1524×3.6576) m lumber referred to as "2by6" in the primary wood industry was evaluated. This assessment is a cradle to gate system with boundaries spanning from the point of raw material extraction in Osun state, to transportation of the lumber product to wood market in Ibadan, Oyo state. The study compared four production scenarios by varying haulage distance and energy source during production at two sawmill facilities located in Ife and Ikire in Osun state. Data obtained from the production system were analysed using GaBi6 software to estimate and classify the emissions into five impact categories. Life Cycle Impact Assessment result (LCIA) showed that Acidification Potential (AP), Global Warming Potential (GWP) and Smog Potential (SP) were the most significant impact indicators observed in the four production scenarios. AP (2.883, 3.352, 3.483, 3.951) kg H+ mole-Equiv, GWP (13.25, 14.44, 15.45, 16.65) kg CO2-Equiv and SP (1.86, 2.15, 2.24, 2.53) kg O3-Equiv. Scenario 4 which involved a longer transportation distance and employed a diesel generator for the milling process showed the least environmental performance. Processes that contributed significant impact were wood waste disposal method employed and the secondary transportation processes during logging activities. In order to achieve a better production system, practices that encourage less waste generation and the use of renewable energy were recommended.

Keywords— LCA, lumber production, environmental impact, wood waste

1 Introduction

Wood is an indispensable engineering material that has served man throughout history (Johnson et al., 2017). People relied on wood for needs varying from farming tools to building materials, fuel, weapons of hunting and warfare (Fuwape, 2003). The rain forest zone of Nigeria is blessed with abundant natural forests because the geographical location in the tropics has naturally favoured growth of trees, which is the source of abundant wood in Nigeria (Johnson et al., 2017). In most industries worldwide, including forest products sector, there is an increasing focus on the environmental, social and economic sustainability credentials of companies and products (FPAC, 2010). Documenting the life cycle impacts of wood processing provides insights for improving system efficiencies and decreasing associated environmental burdens (Pryor et al., 2017).

Life Cycle Assessment (LCA) is a technique for assessing the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal (ISO 2006). LCA methodology is increasingly being used as an important and effective tool to support multiple types of sustainability goals and has been applied to a wide range of processes and sectors (FPAC, 2010). Various studies have being conducted on the environmental performance of wood products. Such studies include LCA of hardwood lumber by the America Hardwood Export Council (AHEC, 2012), cradle-to-gate life cycle assessment of wood pellet production by (Aremu et. al., 2014), and softwood lumber production by (Puettmann et al., 2009). LCA has also been employed in some agricultural products such as vegetable oil production by (Bamgbade et al., 2014), oil palm production in Malaysia (Muhammad and Sharaai, 2015), cradle to gate poultry production system in developing country (Ewemoje et al., 2013).

Lumbering, which is the felling of trees for timber, has been identified as one of the primary occupations that lead to deforestation of the environment (Igben and Ohiembor, 2015). The processes of tree felling, log transportation, log conversion and waste management methods employed by sawmill industries can have impact on the environment. This study document from cradle to gate the environmental impact of producing a (0.0508×0.1524×3.657) m lumber product referred to as 2by6 in the primary wood industry. The assessment employed both primary and secondary data to quantify the environmental impacts of *Terminalia superba* (Afara) into relevant impact categories throughout the production chain from forest in Osun state to wood market in Ibadan, Oyo state. LCA result showed that the environmental impact was dominated by waste management practice whereby sawdust generated is disposed by open combustion leading to significant impact on Acidification Potential (AP), Global Warming Potential (GWP) and Smog Potential (SP). Recommendation such as the reuse of wood waste can have both environmental and economic benefit.

2 Materials and Methods

This LCA documents the environmental burden associated with the production of a lumber product dimensioned at 0.0508×0.1524×3.6576 m of *Terminalia superba*as the functional unit. Data were collected from two sawmill facilities at Ikire and Ife in Osun state Nigeria for scenario modeling, while secondary data from relevant literatures were employed to obtain the logging residues generated during logging activities.

2.1 Study Area

The system boundaries for this assessment spanned between forest sites in Osun state and Bodija wood market in Ibadan. Two sawmill sites located at Ikire (7°25′47″N, 4°10′47″E) and Ife (7°25′31″N, 4°34′11″E) respectively were assessed. These sawmill use methods and technology commonly practiced among wood

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processing industries in Osun state and other region in south-west Nigeria. Timber harvest site for Ikire sawmill was estimated at 80km away from the sawmill facility. After logs have being processed into lumber, they are transported to wood market in Ibadan. Bodija wood market (7°23′′N and 3°55′E) is the largest sawn wood market in Ibadan. It covers more than 10 hectares of land area and it is a center of commerce for lumber product processed in neighboring states (Aremu et al., 2015). It is divided into ten zones with 144 sheds in each zone. Haulage distance was estimated using a GPS enabled mobile device to obtain coordinates , while Google map was used to estimate the distance between the sawmill facilities and the wood market. The distances between Ife and Ikire to Ibadan were approximately 91km and 42 km respectively.

2.2 Waste Generated and Energy Consumed during Log Conversion.

At the sawmill facility, volume of log, sawdust, bark and slab were estimated using Smalian's formula, while energy consumed by bandsaw was estimated by multiplying machine power rating with operation duration. Electrical grid mix for Nigeria was modeled in GaBi software using data adapted from the International Energy Agency (IEA) as 18% hydro and 82% natural gas (IEA, 2015).

2.2.1 Estimating the Total Volume of Log (V)

$$V = \left(\frac{S+s}{2}\right)H \qquad \dots (1)$$

Where

S = Cross-sectional area of Large end of log

s = Cross-sectional area of small end of log

L = Length of log

Where S is given as $0.7857D^2$ and D is the diameter of larger end of log while s is $0.7857d^2$ and d is the diameter of the smaller end of log.

2.2.2 Estimating Volume of Bark (Vb)

The volume of bark was estimated using the following formula

$$V_b = V_{o.b} - V_{i.b} \qquad \dots (2)$$

Where:

$V_{o.b}$ = Total volume of log over bark

$V_{i.b}$ = Total volume of log measured inside bark

$V_{i.b} = 0.7857(d_{i.b})2L$ and $d_{i.b} = d_{o.b} - 2Bkt$

L = Length of log and Bkt = Bark thickness

2.2.3 Estimation Volume of Sawdust (Vs)

Volume of sawdust was estimated by multiplying the width of the cut surface by log length and blade thickness (Bt).

$$Vs = W \times 3.6576 \times Bt \qquad \dots (3)$$

2.2.4 Estimating Energy Consumed by Bandsaw

The total energy required by functional unit of (0.0508×0.1524×3.6576) m lumber product was calculated by multiply the band saw (CD5) power rating of 22KW by the average operation duration in hours.

$$\text{Energy required} = \frac{22KW \times 0.1333hrs}{5} \qquad \dots (4)$$

2.3 Scenarios Modeling

Four production scenarios were compared by varying energy source from National grid and a 30KVA diesel power generator between the two sawmill facilities.

Table 1. Description of scenarios for the four production systems

Scenarios	Power Source	Sawmill Location	Scenarios Description
Scenarios 1	3 Phase, 220V power grid	Ikire, 42Km	Production at Ikire energy from grid.
Scenarios 2	30KVA diesel generator	Ikire, 42Km	Production at Ikire, energy from diesel generator.
Scenarios 3	3 Phase, 220V power grid	Ife, 91Km	Production at Ife, energy from grid.
Scenarios 4	30KVA diesel generator	Ife, 91Km	Production at Ife, energy from 30KVA diesel generator.

2.4 Life Cycle Impact Assessment (LCIA) of Lumber Product

The LCIA phase establishes links between the life cycle inventory results and potential environmental impacts. Its aim is to identify the emissions associated with the production chain as specified by the boundary of the assessment. The production process started with a 40kg of raw material (timber stand) and to obtain a 16kg of (2×6in) lumber product dimensioned at (0.0508×0.1524×3.6576) m. A 1.5hp chainsaw was employed during timber felling and removal of tree tops and branch to obtain a round wood of 3.7 meters long.

The round woods (logs) were transported to the mill yard by road with the logging truck (lorry) estimated at a payload of about 7500 Kg. At the milling process, a 0.33m diameter log produced 5 lumber products each measuring16 kg, 2.8kgsawdust, wood slab of 10kg and bark at 1.7 kg. Bark and sawdust were estimated at about 8 and 4 percent of the log respectively. All the materials output during the production of lumber are valuable products that can be used for other purposes. The bark produced is usually collected and used for domestic purpose. Wood slab generated during sawing operation were piled for other secondary wood products. Lumber product which is the major product is usually transported to the wood market depending on market demand. Sawdust is mostly disposed by combustion at the sawmill site. This LCA assumed that all sawdust generated during lumber processing was disposed by incineration as it often has little or no further use.

3 Results

3.1 Life Cycle Inventory Result

The inventory analysis shows the total inputs and outputs related to materials and energy flows of a (0.0508×0.1524×3.6576) m (2by6) lumber product. The summary of the inventory result is shown in Table 3. It was estimated that about 20 percent of the forest residue generated occurred during the removal of tops and branches of the economic tree to obtain logs. Sawdust and bark were generated during the bulking process and the impact of their production and disposal were included in the LCA. In the inventory result analysis, the energy content of the renewable resources (wood biomass and hydro) was 935 MJ which was 90.2% of the total primary energy demand while non-renewable energy resources (natural gas and crude oil) was 91,2 MJ at 9.8%. The total primary energy demand is the energy content of the material resources used up in the production process of six pieces of the functional unit. This also provides information on the resource depletion potential of the production system.

Table 2: Summary of the inventory result associated with a (0.0508×0.1524×3.657) m lumber product.

Parameters	Amount	Unit
Primary Energy Demand		
Renewable energy resources	935	MJ
Non- renewable energy resources	91.2	MJ
Material Resources		
Renewable resources	1090	Kg
Non Renewable resources	17.9	Kg
Emissions		
Emissions to Air	17.6	Kg
Emission to Fresh water	1.1E3	Kg
Emissions to Sea water	0.00166	Kg
Emissions to Agricultural Soil	1.98E-6	Kg
Emissions to Industrial Soil	1.48E-8	Kg

3.2 Lumber Production Impact Interpretation

The Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) was used to analyse the results of the four scenarios considered for the production of the functional unit on GaBi LCA software. Three of the significant impact categories discussed here are acidification, global warming, and ozone depletion potential.

3.2.1 Acidification Potential (AP)

Acidification is the increasing concentration of hydrogen ion (H^+) within a local environment. The total acidification potential caused by the production of a 0.0508×0.1524×3.657m lumber was 2.883Kg H^+ mole equivalent. Chart shows that transportation of production materials from the forest to sawmill resulted in the most contribution to acidification potential. Acidification from road transportation was due to emission of SO_2 and NO_x gases from the combustion of fossil fuel by the logging truck. The transportation of product from sawmill to wood market and removal of tree tops and branches using gasoline powered chain saw both resulted to 0.546 and 0.577 Kg H^+ mole equivalent respectively.

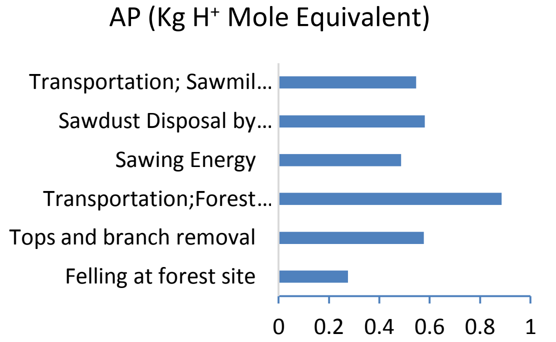

Fig. 1: Acidification Potentials for a Unit Production of (0.0508×0.1524×3.657) m lumber product for Scenario 1

3.2.2 Global Warming Potential (GWP)

Global warming is an average increase in the temperature of the atmosphere near the earth's surface which can contribute to changes in global climate patterns. (Bare, 2014). The total global warming potential caused by the production of a functional unit was 13.25Kg CO2 equivalent. Fig. 2 showed that the disposal method of sawdust waste by open combustion contributed the highest impact on GWP. The felling process using gasoline powered chain saw has the lowest GWP of 0.38 Kg CO2. This was due to a relatively smaller amount of fuel combusted by the chainsaw during felling.

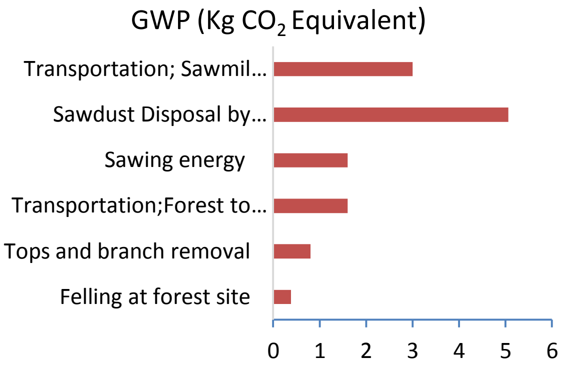

Fig. 2: Global Warming Potentials for a Unit Production of (0.0508×0.1524×3.657) m lumber product for Scenario 1

3.2.3 Smog Formation Potential (SP)

Smog can result in a variety of respiratory issues which including increasing symptoms of bronchitis, asthma, and emphysema (Bare, 2014). The total smog potential for the base scenario was 1.86 Kg O3-Equivalent. Secondary log transportation from forest to mill yard showed the highest contribution to smog potential followed by sawdust disposal by incineration. Transportation of lumber product from sawmill to wood market also shows a considerable amount of smog on the environment while timber felling process at forest site gave the lowest contribution to smog Potential. Comparison between scenarios 1 and 2 revealed that even though both scenarios involved equal distance, scenario 2 gave a higher overall contribution due to the emission caused by diesel powered generator. Scenario modeling inferred that using of fossil fuel has an overall contribution to smog formation than renewable energy source.

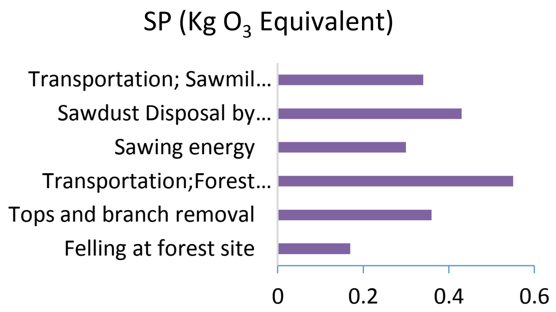

Fig. 3: Smog Potentials for a Unit Production of (0.0508×0.1524×3.657) m (2×6inch) lumber product for Scenario 1

4 Conclusion and Recommendations

In other achieve a cleaner production, the environmental burden related to wood harvesting, conversion, use and disposal will needs to be understood and quantified. LCA result showed that environmental impact was dominated by waste management practice whereby sawdust generated is disposed by open combustion leading to significant impact on Acidification Potential (AP), Global Warming Potential (GWP) and Smog Potential (SP). Also, LCA result revealed a relatively lower impact on Eutrophication Potential (EP) and Ozone Depletion Potential (ODP).

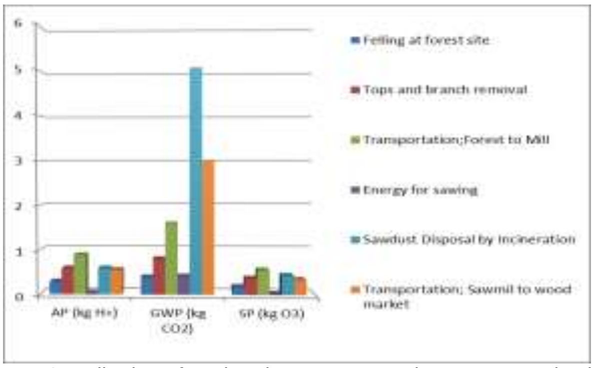

Fig. 4: Contribution of each unit processes on impact categories by (0.0508×0.1524×3.567) m lumber product.

In the scenario modeling, haulage distance and energy source for the milling process where varied among the two production site. Higher transportation distance demanded more fuel which resulted in a higher environmental impact. Energy generation from diesel fuel resulted in more emissions compared to the use of electricity from the national grid modeled from the data obtained from the International Energy Agency as the combination of hydro and Natural gas.

Recommendations such as reduction or replacement of fossil fuel with renewable fuel, good management on logistics during logging, upgrade to the logging trucks to fulfill the higher vehicle emission standards, and a properly planed concentration point. The reuse of wood waste generated at sawmill can add economic value to the lumber processing industries by using it in the production of engineered wood product such as fiberboard. Complete life cycle assessment from cradle to grave which includes wood product utilization and end of life of wood product should be conducted to better understand and avoid burden shifting whereby impact minimized at one stage of LCA is included at other stages. Development of LCA data for the wood product industry will help improve lumber production assessment.

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