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Carbon footprint of lumber production from falcata [*Falcataria moluccana* (Miq.) Barneby & J. W. Grimes] in the CARAGA Region, Philippines

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ABSTRACT. The CARAGA Region, known as the "timber corridor" of the Philippines, is well known for its Industrial Tree Plantations (ITPs) that produce falcata [*Falcataria moluccana* (Miq.) Barneby & J. W. Grimes] lumber for the veneer and plywood industry. However, the carbon footprint of this falcata-based industry has not yet been accounted for. This study calculated the greenhouse gas (GHG) fluxes of its production chain – from harvesting to processing – following the IPCC (2006) and EMB (2011) guidelines for greenhouse gas inventory that trace the sources of emissions at all stages of operation. This study estimated that the total emissions for a 1 m^3 kiln-dried lumber were about 0.317 Mg CO_2e m^{-3}. The greatest emissions came from major transportation from plantation site to sawmill (49%) while the lowest emissions came from sawmill processing (12%). This was mainly due to the use of waste materials for the boiler, which lowers the sawmill's electricity consumption. Opportunities to reduce emissions within the production chain were also identified, for instance during sawmilling where air drying and more efficient vehicles and equipment may be used. This study serves as a baseline in determining the emission contribution of other types of wood products using other tree species. Future studies, however, will be further enhanced by incorporating the carbon footprint of the end-of-life emissions of lumber products to establish its full cradle-to-grave life cycle.

Keywords: carbon stocks, CO_2e, falcata lumber, GHG inventory

INTRODUCTION

During harvest, carbon is either taken out of the forests as harvested wood products (HWPs) or retained as logging residues (Kloehn & Ciccarese 2005). Wood products, therefore, enhance the carbon sink capacity of forests by extending the period that CO_2 is excluded from the atmosphere and at the same time, by encouraging forest growth (CEI–Bois 2006).

HWPs are not carbon sinks but are 'carbon reservoirs' where carbon remains fixed until the products decay or are burned. Therefore, a decaying or burning wood product is a source of greenhouse gas emissions, specifically CO_2 (UNFCCC 2003). Studies show that HWPs can store carbon in both short or long terms (2 mos for newspapers and 75 yrs for structural wood) (CEI–Bois 2006). The period in which carbon is stored will differ depending on the product itself and its uses (IPCC 2006).

Harvesting wood products result in direct greenhouse gas emissions from slash and expose soil to oxidation. The harvested wood will then enter further transformation (manufacturing, use, and disposal) where carbon emissions may occur at different levels in different stages. The flow of carbon from forests to HWPs can be traced in four main steps: "transfer of carbon from forests to harvested roundwood; transfer of carbon from roundwood to intermediate products; transfer of carbon from intermediate products to secondary and/or end-use products; and transfer of carbon from end-use products to SWDS (solid waste disposal site) or the atmosphere" (UNFCCC 2003, 8). The role of forests and the forestry sector, therefore, in reducing the atmospheric carbon is influenced by the life span and end-use of HWPs derived from it – as the emission of carbon occurs throughout its life cycle (Gower 2003).

Lumber as a harvested wood product is produced involving different operations. It includes harvesting, minor and major log transport, and lumber processing in sawmills, which are all accompanied by carbon emissions from different energy sources and electricity consumed, as well as, wastes generated along the process. Such processes require greenhouse gas (GHG) inventory for a realistic estimation and statistical representation of the potential carbon contained in the wood product. However, carbon emission estimation of wood products during its lifetime is affected by the decay rate or fraction of carbon lost as emissions (Winjum *et al*. 1998), the fraction of carbon allocated to long-lived products (Dias *et al*. 2007), and waste treatment practices (Pingoud 2008; Skog 2008).

Wood industries are required to respond to global climate change through environmental compliance on GHG emissions.They need to understand the quantity of emissions from activities to purchase sufficient carbon permits to meet legislated obligations or to report emissions to interested stakeholders. Industries, therefore, need to develop processes and procedures to capture and measure the necessary data to account for their GHG emissions. Thus, this study quantified the GHG emissions of the Falcata lumber industry in each phase of production in an attempt to trace the least and highest GHG emissions within the product's life span.

METHODOLOGY

To help mitigate climate change, both government and private sectors establish forest plantations to cope with the increasing demand of the wood industries for raw materials while addressing accompanying ecological concerns. In the Philippines, the CARAGA Region, considered as the "timber corridor" of the country, is where most of the industrial tree plantations (ITPs) were established as one major scheme used in the country to arrest the rapid denudation of natural forests, as well as, meet the demand for a sustained volume of wood needed by wood-based industries. According to the 2016 Philippine Forestry Statistics (PFS), the CARAGA Region produced between 62% and 72% of the total production of plantation logs over the last 5 yrs (FMB 2016), predominantly that of falcata [*Falcata moluccana* (Miq.) Barneby & J.W. Grimes (formerly *Paraserianthes falcataria* (L.) Nielsen)].

This study focused on the GHG inventory of using falcata species in the production of lumber from the forest to the end-product (**Table 1**). It also included wastes generated in the operation, fuel consumed per operation, and electricity consumption during sawmilling.

Due to budgetary limitations and time constraints, the default values on carbon stocks in harvested wood from falcata plantations were calculated based on the harvested wood during the study period (January to September 2018) and compared to existing literature, particularly local and regional studies cited. It does not include biomass assessment from plantation sites. IPCC default values or values from related studies conducted locally were used for wastes in the absence of country data such as carbon emission factors. Future research work may be focused on the detailed information on carbon emission from plantation sites including carbon stored or emitted from specific activities on biomass, wastes, and other by-products.

The inventory follows the IPCC Guidelines (2006) and Environment and Management Bureau (EMB) (2011) tracking manual for GHG inventory. IPCC default values for emission factor were used per type of fuel, electricity, and equivalent emissions for carabao manure. The identified wood density of falcata was used to calculate emissions from wastes left to decay and those used for the boiler.

Table 1. Inventory data collected from the survey.

Process	Inventory data
Felling process	Average age of the log, type of machine used to harvest, working hours, type of fuel, and fuel consumption
Minor log transport	Mode of transportation, type of fuel and fuel consumption, mileage, carabao manure during hauling operation
Major log transport	Mode of transportation, type of fuel and fuel consumption, mileage, age of truck used
Sawmill	Type of machines used, working hours of the machines, type of fuel and fuel consumption, volume of lumber product, electricity consumption

GHG emissions per operation were calculated considering the system boundary from harvesting point to drying of the finished product. **Figure 1** shows the operational boundary of the study while the activity data were collected based on the sample surveys in each operation.

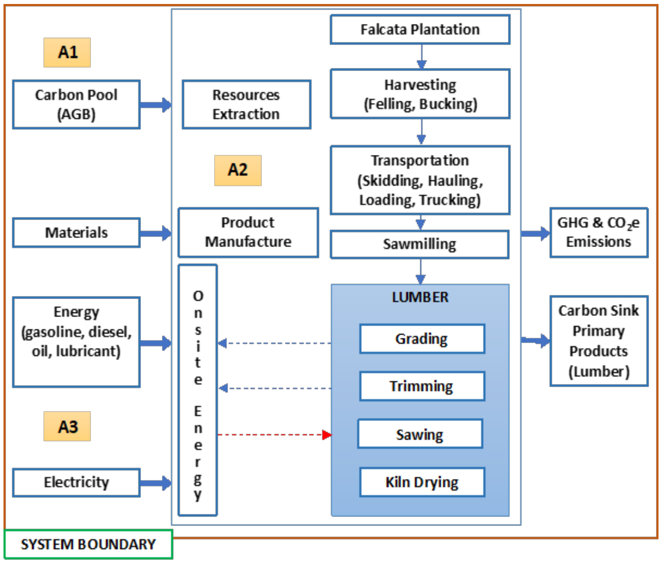

Figure 1. Operational boundary for falcata lumber production.

The system boundary defines the unit processes in the system. The unit systems included were inputs and outputs in the main processing sequence, transportation, production and use of fuels, electricity, as well as wastes generated. It includes resource extraction or harvesting operation (A1), minor and major log transportation (A2), and manufacturing or primary wood processing (A3). The harvesting operation (A1) excludes the repair and maintenance of the equipment used. The transportation of logs (A2) from the stump site to the mill was accounted for with the veneer and lumber manufacturing (A3). The product manufacturing was modelled as a multi-unit process separating the veneer and lumber production up to drying operation. Layup, pressing, trimming, final packaging, and by-products were not considered in the study. Outputs of the system boundary include the primary products (*i.e.* veneer and lumber) and GHG emissions.

The inventory was done and analyzed following the basic principles of IPCC (2006) and EMB (2011) inventory manual for tracking GHGs. On the other hand, the CO_2 emission factors and other default values were sourced from the same sets of literature including the International Energy Agency (2011). Updated emission factors were used to calculate the CO_2 eq units. On the other hand, the global warming potential (GWP) was calculated using the values of the IPCC Fifth Assessment Report (2014). The wood density of falcata (280 kg m^{-3}) was used to calculate the emissions from wastes left to decay in the forest and mill wastes. **Table 2** summarizes the GWP for each GHG gas according to the fifth assessment report of the IPCC (2014).

Data collection

Detailed and relevant data on each stage (harvesting, transport, and sawmilling operations) were collected through in-depth interviews with farmers, transport groups, and sawmill operators. In harvesting operations, the gasoline consumption for chainsaws and lubricant for the guide bar was computed. Data on the minor (from the stump site to the roadside) and major (from the roadside to the sawmill) log transport, including fuel and oil consumption of vehicles used, were gathered from farmers and transport operators involved in harvesting and hauling from January to September 2018. For the wood processing operation, lumber production, and fuel, oil, and electricity consumption from cutting to drying operations were accounted for.

Table 2. Global warming potential of selected greenhouse gases.

Greenhouse gas	Chemical formula	GWP
Carbon dioxide	CO2	1
*Methane	CH4	28
*Nitrous oxide	N2O	265
Hydro fluorocarbons	HFCs	4–12,400
Per fluorocarbons	PFCs	6,630–11,100
Sulfur hexafluoride	SF6	23,500

**Methane and nitrous oxide emission factors for grid electricity were derived from the national grid, International Energy Agency, and IPCC (2006). Other GHG gases' GWPs were sourced from IPCC (2014).*

A list of Industrial Tree Plantations (ITPs) with 5–8 year rotation ages was obtained from the private tree plantation ownership certificate (PTPOC) submitted to 10 Community Environment and Natural Resources Offices (CENRO) of the Department of Environment and Natural Resources (DENR) in the CARAGA Region (Nasipit, Cabadbaran, Bayugan, Bunawan, Loreto, Talacogon, Surigao City, Cantilan, Bislig, and Lianga). From a list of 616 registered tree farmers engaged in harvesting operations in the region, respondents were identified using the stratified random sampling approach. The same procedure was done for those involved in minor and major log transport operations with operations between January and September 2018.

A list of registered wood processing plants (WPPs) in 2018 was also gathered from the same government office. These WPPs were grouped under four (4) categories: a) integrated (plants with a daily rated capacity (DRC) of at least 18m^3), b) veneering (primary wood processing plant that converts logs into standardized sheets, either by peeling or slicing), c) mini-sawmill (those with lower than 18m^3 DRC capacity), and d) veneering and mini-sawmill (those with combined capacity, *i.e.*, with <18m^3 DRC, but are also producing veneer). Sampling for 30 replicates under each sawmill category was randomly conducted for fuel used and electricity consumed during milling operations (from log grading to drying).

GHG emission calculation

The net GHG fluxes for the entire production chain of falcata plantation were computed to assess how much CO_2 is absorbed or released during the process and whether the net is positive or negative CO_2 flow. Positive net CO_2 fluxes mean that the ITP operation is more of carbon absorber while negative net flows connote that the project is a carbon emitter.

The study computed the CO_2 net emissions or uptake value based on the total CO_2 stored per volume of lumber produced out of the total volume of logs as input variable for the wood processing operation. The following generalized equations were used to calculate GHG emissions for each identified emission sources and the net GHG fluxes:

Equation 1:

Total CO₂e Emissions *= ∑(Activity data x CO2 emission factor x 1) + (Activity data x CH4 emission factor x 28) + (Activity data x N2O x 265)*

Equation 2:

Net GHG Fluxes *= CO2e Stock from lumber product – CO2e footprints from operations*

The carbon stored in the product at the manufacturing stage and the identified wood density for falcata (280 kg m^{-3}) serve as basis for the analysis. The carbon stored may then be considered against the emission from operation to come up with the net GHG fluxes for lumber production.

RESULTS AND DISCUSSION

The GHG footprint inventory involves the calculation of the GWP impact of kiln-dried lumber production based on inventory data. The total carbon footprint is presented in terms of Megagram of CO_2 equivalents per cubic meter (Mg CO_2e m^{-3}).

Considering the total CO_2e during the process, 23% of the emissions were determined to have come from harvesting (includes emissions from fuel used in chainsaws). Minor log transportation that mostly used carabao for hauling accounted for 20% while major log transportation that used ten-wheeler trucks had the highest GHG emission of 56%.

Harvesting operation

Harvesting operations involved felling, bucking, and transporting of logs from the stump site to the roadside (minor log transport). Key informant interviews results showed that new chainsaws (≤ 5yrs old) can produce around 6 m^3 of log per 1 L of gasoline consumed (6 m^3 logs per 1 L gasoline). Older chainsaws (> 5yrs old), on the other hand, can only produce around 2 m^3 of logs for the same amount of gasoline. On the other hand, 100 mL of oil is used for every L of gasoline used while 1 L of lubricant for the chainsaw is needed for every 18 m^3 of logs produced.

The source of GHG emissions from the harvesting operation came from the volume of fuel used for the chainsaw (**Table 3**). The total emission due to harvesting practices was estimated at 1.701 Mg CO_2e representing 12.5% of the total emissions.

Table 3. Average GHG and CO_2e emissions from fuel used during harvesting operation (in Mg m^{-3}).

Fuel type	Emissions (Mg m^{-3})			Total	CO_2e (Mg m^{-3})
	CO_2	CH_4	N_2O		
Gasoline	1.392	0.002	nil	1.394	0.001
Oil	0.160	nil	nil	0.160	nil
Lubricant	0.147	-	-	0.147	nil
Total				1.701	0.001

Note: Values with ≤0.0001 are considered nil.

Minor log transport operation

Minor log transport is done commonly using carabao, manual hauling, motorcycle (*habal-habal*), and small trucks (elf-type) depending on the length of haul, size of load, and road conditions from the stump site to the roadside. **Table 4** summarizes the GHG emissions from fuel used during major log transport.

According to the tree farmers, minor log transport commonly commences about one week after bucking. The mass loss of 10% of moisture after one week of drying lightens the logs and makes for easier handling (Simpson & Ward 2001). Also, it results in energy savings of approximately 25% when lumber is kiln-dried.

Table 4. GHG emissions from fuel used during minor log transport operation (in Mg m^{-3}).

Fuel type	Emissions (Mg m^{-3})			Total
	CO_2	CH_4	N_2O	
Gasoline				
Habal-habal	1.600	0.002	nil	1.602
Elf	0.940	0.001	nil	0.941
Oil				
Habal-habal	0.039	nil	nil	0.039
Elf	0.014	nil	nil	0.014
Total	2.593	0.003	-	2.596

Note: Values with ≤0.0001 are considered nil.

Major log transport operation

Major log transport is the hauling of logs from log landing or roadside to the sawmill in large quantities. Energy consumed during transportation between harvesting and manufacturing was computed based on actual distance to the production facilities. Out of the 250 farmer respondents, 52 were engaged in major log transport activity from January to September 2018. Of the total, 54.4% delivered falcata logs directly to millers while 45.2% of respondents sold logs at the roadside where buyers converge and pick-up the logs to be delivered to sawmills either in CARAGA Region or in Cagayan de Oro. Choice of place of delivery depends on the price determined by the wood processors. Very few are sold to middlemen.

Ten-wheeler trucks (*i.e.*, Isuzu or Mitsubishi trucks) with a maximum capacity of 27,000 kg are widely used in the region. The trucks ranged in ages from 2–20 yrs. The fuel efficiency of these trucks was considered based on age and distance travelled. **Table 5** summarizes the GHG emissions from fuel used during major log transport.

Table 5. GHG emissions from fuel used during the major log transport operation (in Mg m^{-3}).

Fuel type	Emission (Mg m^{-3})			Total
	CO_2	CH_4	N_2O	
Diesel	3.877	nil	0.001	3.877
Oil	0.153	nil	nil	0.153
Total	4.030	-	0.001	4.030

Note: Values with ≤0.0001 are considered nil.

Wood processing operation

Wood Processing Plants (WPPs), also known as sawmills, are categorized as 1) integrated, 2) veneering, 3) mini-sawmill, as well as 4) veneering and mini-sawmill. Due to lack of time and financial resources, only 34% of the total sawmills were inventoried in term of energy (*i.e.*, gas or diesel) and electricity utilized during the operations. During the study period, only five sawmills that had drying facilities for lumber and veneer (4 integrated and 1 veneering and mini-sawmill) were operational. Based on the interview, some sawmills had adopted clustering schemes in procuring raw materials. Logs and some unfinished products such as lumber were obtained by co-sharing with other sawmill plant owners through mass purchases.

Table 6 summarizes the energy-related emissions from fuels used in lumber production within the sawmills. Results of the inventory also show that machines used in lumber production make use of about 50.910 kWh electricity, which produces about 0.015 Mg CO_2e m^{-3}.

Table 6. Energy-related emission for lumber production (in Mg m^{-3}).

Fuel type	Emission (Mg m^{-3})			Total
	CO_2	CH_4	N_2O	
Gasoline	0.883	0.001	nil	0.884
Oil	0.011	nil	nil	0.011
Lubricant	0.028	-	-	0.028
Total	0.922	0.001	-	0.923

Note: Values with ≤0.0001 are considered nil.

GHG emissions and C stored in lumber production

Emissions for minor and major log transport varied depending on the mode of transport combinations used. The potential C storage was calculated based on the volume of the final product (lumber) produced out of the harvested wood using the wood density of falcata. Net GHG emission was derived by deducting the amount of C stored from the total GHG emissions of the four activities.

Since 1 t carbon produces 3.67 t CO_2e, the total CO_2e emission from lumber produced resulted in 0.462 Mg CO_2e m^{-3} from C stored. This value was deducted by the amount of emissions from its operations resulting in net emissions of 0.317 Mg CO_2e m^{-3} as summarized in **Figure 2**.

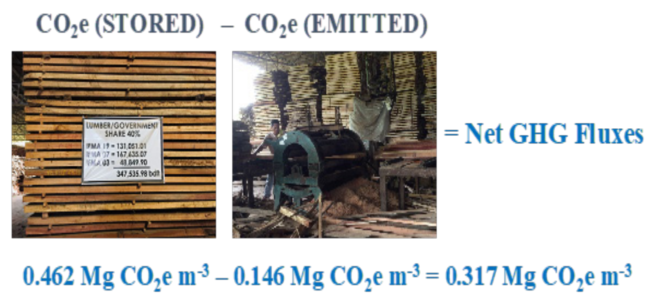

Figure 2. Net GHG emission for lumber production (Mg m^{-3}).

Based on the study, the total GHG emissions in the drying process was 10% and the main reason for the reduced figure was the use of mill wastes for the boiler, hence less energy used during the process. On average, major log transportation accounted for high emissions due to many factors including the distance between the roadside (pick-up point for logs to the sawmill), the condition of the ten-wheeler trucks used, and lack of transport planning, among others. This is consistent with earlier findings where the emissions from transportation were recorded to be the highest compared to emissions from harvesting and processing.

CONCLUSION AND RECOMMENDATIONS

The carbon stored in HWPs such as lumber is an important part of the industry's impact on the global carbon balance. The amount of carbon stored in lumber as a product is larger than the amount emitted through its production stages, thus proving that lumbers are carbon sinks rather than carbon emitters. This study demonstrates that broad analytical approaches incorporating different farmer's practices in conducting the four operations are necessary to comprehensively evaluate the GHG emissions of the falcata-based lumber industry in the CARAGA Region.

Encouraging tree farmers to adopt environment-friendly practices and use cost-effective equipment for the operations will lead to benefits that may accrue in the long run, not only to the end-users but also to the whole society. The greatest opportunities for improvements in terms of emission reduction are associated with the efficiency of the vehicles used for transport operations, both minor and major, and the distance between the roadside to the sawmill. Locating sawmills close to existing plantations and fuel efficiency of vehicles used may reduce emissions from major log transport operation.

Future research in this area should consider the integration of biomass and soil carbon models to estimate carbon change resulting from biomass harvest. This is to further understand the total impact of wood production in ecosystem carbon stocks since this study only considered standing trees for forest biomass and excluded other carbon pools and soil carbon impacts.

This would help inform the stakeholders and ensure that the utilization of forest resources to reduce climate change does not have unintended consequences on the ecological health of forests.

Future research should include a full life cycle assessment of the wood production chain, and a forest landscape carbon balance analysis to come up with the overall GHG emission in the whole process.

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