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ESTIMATION OF CARBON STORAGE IN HARVESTED WOOD PRODUCTS IN THE NEXT 200 YEARS: A SENSITIVITY ANALYSIS OF DIFFERENT LIFE CYCLE SCENARIOS.

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ABSTRACT

Trees can be harvested and re-grown based on sustainable forest management plans while the carbon stock in the timber from harvested trees could be retained for years in the form of wood products to limit the release of carbon back to atmosphere. The process of storing carbon for longer period in long lived harvested wood products have been recognized by the United Nations Framework Convention on Climate Change (UNFCC) as one of the mitigating measure under Land Use, Land-Use Change and Forestry (LULUCF) categories. The carbon stock in harvested wood products has been considered by various countries in their national accounting processes. There have been several studies by various researchers to estimate the carbon stock in harvested wood products pool. This paper uses life cycle analysis to trace the fate of carbon bound in harvested wood products produced from a mature stand of *Dalbergia sissoo* trees until most of the carbon is released back into the atmosphere. This is followed by a sensitivity analysis with twelve different scenarios to analyze the effect of change in terminal use and half life patterns on the carbon stock with respect to passing years.

Keywords: Harvested wood products, Life cycle analysis, Sensitivity analysis.

INTRODUCTION

Rising levels of carbon dioxide gas in the atmosphere from anthropogenic sources raises the temperature of earth leading to enhanced green house effect (S. Biswas et al., 2014). The changing concentration of atmospheric carbon is majorly attributed to fossil fuel combustion, cement production industries (Marland et. al., 1995; Keeling, 1994) and deforestation coupled with other land use change (Houghton, 1993a). This fast changing climatic conditions makes the world prone to enhanced disaster risk and extreme weather conditions (IPCC, 2007). . In 1996, Brown and many other scientist pointed out that forest management activities could play a major role in mitigation the effects of global climate change by arresting the atmospheric carbon dioxide (CO_2) (Brown et al., 1996). Intergovernmental Panel on Climate Change (IPCC) recognizes trees to store about 80% of all the above ground and 40% of all the below ground terrestrial organic carbon (IPCC,2001). Carbon is sequestered and harvested in trees while it can remain stored in harvested wood products for longer time to displace carbon dioxide emissions from fossil fuel combustion (Schlamadinger and Marland,1999). Both the above mentioned processes have been recognized by UNFCCC and IPCC as an effective strategy for mitigating the increase of carbon dioxide in the atmosphere (Nunery and Keeton,2010; Nabuurs and Sikkema, 1998). There have been various studies to demonstrate methodologies to include the carbon stored in harvested wood products under national carbon accounting of various countries excepting India (Haripriya,2001). The study uses simulation based life cycle analysis in twelve different scenarios to trace the fate of carbon bound in the products produced from a mature stand of 13515 *Dalbergia sissoo* trees until most of the carbon is released back into the atmosphere. The sensitivity analysis has been carried out to find out the effect of change in terminal use and half life of the wood products keeping the decay rate constant.

METHODOLOGY

A simple montecarlo based Life Cycle Assessment (LCA) model was used to calculate the net flux of carbon stocked in 13515 s*issoo* trees from Saharanpur (9758 trees) and Bijnor (3757 trees) forest areas of Uttar Pradesh state through the harvested wood products pool back to atmosphere over a period of 200 years. This was computed as the difference between carbon harvested annually and the release of carbon from processing, burning and decomposition of forest products. The biomass accumulation and carbon sequestration of mature *sissoo* trees was estimated based on the growth data on diameter at breast height (cm) and the height (m) of equal or above 30 years old trees, recorded in field. This data was collected from the forest areas managed by the forest department covering 429 sites in the year 2009. The trees were selected according to the harvest order issued by the divisional forest officer for biomass accumulation and carbon stock studies. Biomass accumulation and subsequent carbon dioxide equivalent (CO_2eq.) values for each age class was calculated as per the methodology recommended by IPCC (2007) using volume equations given by Bohre et al. (2012). This value was further multiplied by the population of the respective age class to quantify the total biomass, total bole biomass and total carbon harvested from the sissoo trees. Estimation of carbon locked and emitted at various stages of lifecycle was calculated by running the simulation coded in Matlab 7.0 software (Bhattacharyya et al, 2013).

The lifecycle of carbon stored in fuel wood and non timber parts (of the *sissoo* trees) is very small and generally gets released in to the atmosphere within first three years of its use (Bhattacharyya et al. 2013; Haripriya, 2001). The total biomass and carbon stored in the boles of 13515 matured sissoo trees in Saharanpur and Bijnor forest areas was estimated to be 29682.41 tones that is equal to 49020.50 tonnes of CO_2eq. (70.45%). The below ground biomass was estimated to be 8426.59 tonnes which is equal to 13916.53 tonnes of CO_2eq (20%) and the total fuel wood (includes leaves too) biomass was 3988.64 tones (9.47%), 6587.23 tonnes CO_2 eq. Only 70.45% of the carbon stocked in bole biomass enters the production process. The bole biomass in the form of timber (with stock of carbon) will be used for carving various wood products and lock the harvested carbon for further more years. During the production process of the wood based SMEs 30% of the carbon was released as waste, of which 6% was used by the labors for personal purposes (cooking fuel) and 24% sold off to the brick kilns and plywood industries, used to fire boilers (Sarkar and Manoharan, 2009; FRI, 1970). In addition CO_2eq. amounting to 46.25% of the carbon entering the production process was emitted as process energy from the fuel and electricity burnt to convert the round wood in to products (Bhattacharyya et al, 2013).

The fraction of carbon that remains locked in various pools from the total carbon entering production process in a year was computed based on the following empirical formula

$$VC_L = VC_{PP} + VC_{LF} \quad \text{. . . . . (1)}$$

Where VC_L is the annual flux of carbon that remains locked before being released in to the atmosphere, VC_{pp} is the carbon stored in harvested wood products pool and VC_{LF} is the carbon in Land fill. The carbon that has left the pool has three terminal use options. It can be recycled in to raw materials (VC_{REC}), burnt as energy (VC_B) or set aside in landfills (VC_{LF}) to decompose slowly. Burning (for energy or as waste) immediately releases carbon into the atmosphere; product recycling returns carbon to the immediate previous age class of the forest products pool; and transfer to landfills lead to carbon release through gradual decomposition. The carbon released from landfills depends on the decay rate of products disposed into the landfills. Therefore carbon remaining in products disposed off into landfills (VC_{LF}) can be expressed by

$$VC_{LF} = VC_{LF} - VC_{D} \quad \ldots\ldots\ldots\ldots(2)$$

Here VC_D is the carbon released into atmosphere due to decay. In India carbon is discarded in open dumps, which has a higher decomposition rate than the modern landfills. Karjalainen et. al.(1994) estimated that the decay rate in landfills is 0.5% per annum. Kurz et.al.(1992) used low decomposition rates between 1 and 2% per year for about 80% of the material stored in them, while the remaining material in landfills decompose even more slowly forming a long term storage of carbon. In absence of studies on decomposition rate of carbon from landfills in India, the present study uses the decomposition rate of 1% per annum as used by Haripriya(2000b), which is more specific to India. VC_{PP} is the carbon stored in harvested wood products pool or the products remaining in use is given by

$$VC_{PP} = (VC_{HAR} + VC_{REC}) - VC_{B} \quad \ldots\ldots\ldots\ldots(3)$$

VC_{HAR} (Volume of Carbon Harvested that enters the production process) was calculated using methods recommended by IPCC (2007). In case of wood products, a survey recorded by Institute for National Science Documentation Centre in 1983, analyzed the municipal solid waste and found that the solid waste do not contain any component of wood products. Hence, the disposal of wood after use as waste in dumps or municipal landfills is negligible at present[1]. All the wood products with long life span like tables, furniture, cots etc., are generally reused (Haripriya,2001).

Products made out of sissoo based on their use are categorized under Short, Medium and Long life spans. The "very short" category is not considered in this study in comparison to Haripriya(2001), reason being very short lived products like paper are not made out of *sissoo.* However saw dust and other wood wastes which are short lived are directly burnt accounting to 30%, is considered in the simulation. The simulation is designed to account the carbon flow from harvested carbon entering the production process to short, medium and long lived wood products till the end of life and finally till its release to the atmosphere. The data on the fate of carbon after they are removed from use, the amount of carbon recycled, burnt for energy and disposed in open-air dumps or landfills is very difficult to obtain. The study takes a clue from some of the earlier studies. According to Haripriya(2000b) the short life span products are assumed to have a half life of 3 years, the medium life span products about 12 years and for Long life span products the half life is considered as 30 years. The Table 1 shows the various parameters used in business as usual scenario as considered by Bhattacharyya et. al.(2013).

Table:1: Parameters used in business as usual scenario.

Scenario	**Distribution of Carbon (%) in products profile**		**Proportion of carbon sent to various terminal use**			**Landfill**	**Half-life's**
	Total Biomass %	Carbon Entering production process %	Recycled %	Landfill %	Burnt %	Decay Rate	
Short	1.02	12	0.00	0.10	0.90	0.1%	3
Medium	6.4	68	0.60	0.30	0.10	0.1%	12
Long	1.9	20	0.85	0.10	0.05	0.1%	30

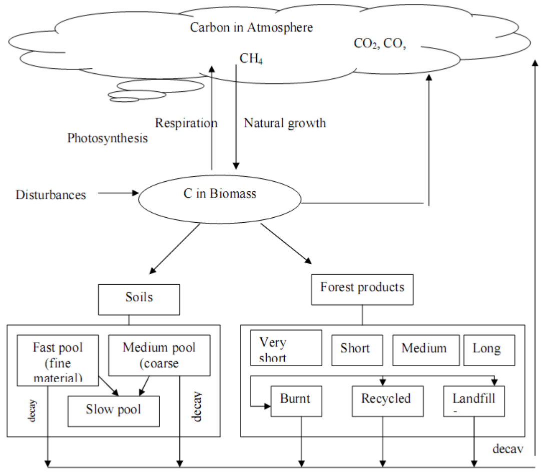

Figure 1: Representation of Carbon flow. Source: Haripriya (2000b).

The Distribution of Carbon (%) in various categories of product is being enumerated by Haripriya (2000b) (Figure 1). The volume of waste generated and burnt to energy (VC_B) during the processing of wood is calculated by physical weighing methods carried out by the researcher in the industry and the results are is in accordance with the publication on Indian forest products by Forest Research Institute (FRI,1970). Further the volume of carbon emitted (VC_E) is calculated by

$$VC_E = VC_{FL} + VC_B + VC_{BTU} \quad \ldots\ldots\ldots\ldots(4)$$

Where VC_{FL} is volume of carbon left out in the forest area and is calculated by summing up the below ground biomass and the biomass of leaves and branches**.** The VC_{BTU} is the volume of carbon burnt after terminal use of products with respect to the half life's .

SENSITIVITY ANALYSIS

The study analyzes carbon stock locked and emitted in various scenarios to explore some of the uncertainties associated with the current available data and assumptions. The sensitivity analysis is to test the robustness of the model and analyze how changes in parameters can affect the model estimates. Twelve different scenarios (S1 to S12) are considered for the analysis with respect to different half-life (life span) and terminal use of the wood products in market. Based on the terminal use the scenarios are majorly divided in to four groups, Energy Intensive, Recycling Intensive, Landfill Intensive and Green Consumerism. In respect to half-life it is divided in to three sets. In respect to decay rate no separate scenarios are generated. Details of each scenario are discussed in the following subsections. Table 2 summarizes all the 12 scenarios and the assumptions briefly.

TERMINAL USE

The effect of change in terminal use on the amount of carbon stored in wood products is explored in four different scenarios. In the energy intensive scenario the assumption is that high costs and difficulty in collection would render it difficult to recover and reuse the short and medium life span products and as a result all the disposed products are burnt (either for energy use or as to reduce waste). However in the recycling intensive scenario, improved collection procedures would facilitate recycling of almost all the products that is removed from use. In the landfill intensive scenario , most of the discarded products are sent to landfill and finally the green consumer scenario, more than 50% of the products are recycled and reused, 30% is sent to landfill (considering the availability of land is very less) and 20% is burnt to retrieve energy. The storyline of Green Consumer scenario describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with policies oriented toward environmental protection and social equity.

HALF-LIFE

To assess the effect of changing the half life of products on the amount of carbon stored in wood products, twelve scenarios are considered. In the first set (S1 to S4) scenario the half life of the products remain same as the business as usual scenario- (Short product- 3years, Medium product- 12 years and Long Products – 30 years), however changes are made in the terminal use. In the second set (S5 to S8) of scenario the half-life of the products are intermediate to the business as usual and the final scenario (Short product- 5years, Medium product- 18 years and Long Products – 45years) and the last set (S9- to S12) the half-life of the products are doubled (Short product- 6years, Medium product- 24 years and Long Products – 60 years). According to Haripriya (2001), shortening or increasing the lifespan of the products by a year or two has marginal effect on the amount of carbon stored in the products.

DECAY RATE

The decay rate has not been changed in any scenario, as no suitable studies were found to support any other decay rates. In landfill intensive scenario, It is assumed that new and better technologies would be adopted to ensure closed and compact landfills which will lead to lowering to the decay rate of the product. Haripriya (2001), assume that products disposed in sanitary landfills where the carbon decays at a much slower rate in 200 years (at the rate of 0.05%/annum). The assumption does not have any sufficient scientific proof and hence is not considered by the author in this study. The decay rate of 1% that is used is an intermittent value of Haripriya (2001) and Kurz et.al.(1992, 1999).

Table 2. Assumptions of the parameters in the twelve different scenarios for sensitivity analysis

Parameters	**S_1 Scenario**	**S_2Scenario**	**S_3 Scenario**	**S_4Scenario**
Description	Energy Intensive	Recycling Intensive	Landfill Intensive	Green Consumerism
Half life	Short- 3 years Medium- 12 years Long- 30 years	Short- 3 years Medium- 12 years Long- 30 years	Short- 3 years Medium- 12 years Long- 30 years	Short- 3 years Medium- 12 years Long- 30 years
Terminal use	Shot- 100% burnt Medium-100% Burnt Long –50% burnt, 0% landfill and 50% recycled	Shot- 50% burnt, 50% recycled. Medium-50% Burnt, and 50% recycled Long –100% recycled	Shot- 50% burnt and 50%Landfill Medium-50% Burnt and 50% Landfill Long –20% burnt, 50% landfill and 30% recycled	Short – 20% burnt, 30%, landfill and 50% recycled Medium - 20% burnt, 30% landfill and 50% recycled. Long- 20% burnt, 30% landfill and 50% recycled.
Decay	1% per annum	1% per annum	1% per annum	1% per annum

Parameters	S_5 Scenario	S_6Scenario	S_7 Scenario	S_8Scenario
Description	Energy Intensive	Recycling Intensive	Landfill Intensive	Green Consumerism
Half life	Short- 5 years Medium- 18 years Long- 45 years	Short- 5 years Medium- 18 years Long- 45 years	Short- 5 years Medium- 18 years Long- 45 years	Short- 5 years Medium- 18 years Long- 45 years
Terminal use	Shot- 100% burnt Medium-100% Burnt Long –50% burnt, 0% landfill and 50% recycled	Shot- 50% burnt, 50% recycled. Medium-50% Burnt, and 50% Recycled Long –100% recycled	Shot- 50% burnt and 50%Landfill Medium-50% Burnt and 50% Landfill Long –20% burnt, 50% landfill and 30% recycled	Short – 20% burnt, 30%, landfill and 50% recycled Medium - 20% burnt, 30% landfill and 50% recycled. Long- 20% burnt, 30% landfill and 50% recycled.
Decay	1% per annum	1% per annum	1% per annum	1% per annum
Parameters	S_9 Scenario	S_{10}Scenario	S_{11} Scenario	S_{12}Scenario
Description	Energy Intensive	Recycling Intensive	Landfill Intensive	Green Consumerism
Half life	Short- 6 years Medium- 24 years Long- 60 years	Short- 6 years Medium- 24 years Long- 60 years	Short- 6 years Medium- 24 years Long- 60 years	Short- 6 years Medium- 24 years Long- 60 years
Terminal use	Shot- 100% burnt Medium-100% Burnt Long –50% burnt, 0% landfill and 50% recycled	Shot- 50% burnt, 50% recycled. Medium-50% Burnt, and 50% Recycled Long –100% recycled	Shot- 50% burnt and 50%Landfill Medium-50% Burnt and 50% Landfill Long –20% burnt, 50% landfill and 30% recycled	Short – 20% burnt, 30%, landfill and 50% recycled Medium - 20% burnt, 30% landfill and 50% recycled. Long- 20% burnt, 30% landfill and 50% recycled.
Decay	1% per annum	1% per annum	0.05% per annum	1% per annum

RESULTS

Sensitivity analysis shows that the carbon stored in short, medium and long life span products is released much earlier in the energy intensive scenarios and landfill intensive scenarios in comparison to recycling intensive scenarios and Green Consumerism scenarios. The highest amount of total carbon locked is seen in landfill intensive scenarios (S3,S7, S11) and is found to be the best option to store carbon for a longer time before it gets released in atmosphere(Figure 3 and Table 3). However India being highly deficit of land resource, cannot afford to spare lands for huge landfills. Thus the next best option is to follow Green Consumerism (S4, S8, S12)which illustrates to store highest amount of carbon locked for longer period of

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time followed by Recycle intensive scenarios (S2, S6, S10). In all the twelve scenarios the highest amount of carbon remains locked in S11 scenario with half-life doubled and practicing landfills as terminal use of the products. Highest amount of carbon that remains locked within the products pool in use is seen in recycling intensive scenarios (S2, S6, S10) (see Figure 2).

Further doubling the lifespan of the products and changing the terminal use pattern to recycling, increases the carbon storage for long period of time by almost two times and increasing the burning of wood products as an option for terminal use by 10% (10 times from business as usual scenario) per annum decreases the carbon storage time by half. However in all the scenarios at any point of time after the primary carbon storage are released (12 years or 24 years) the amount of carbon emitted is always higher to the amount of carbon that remains locked.

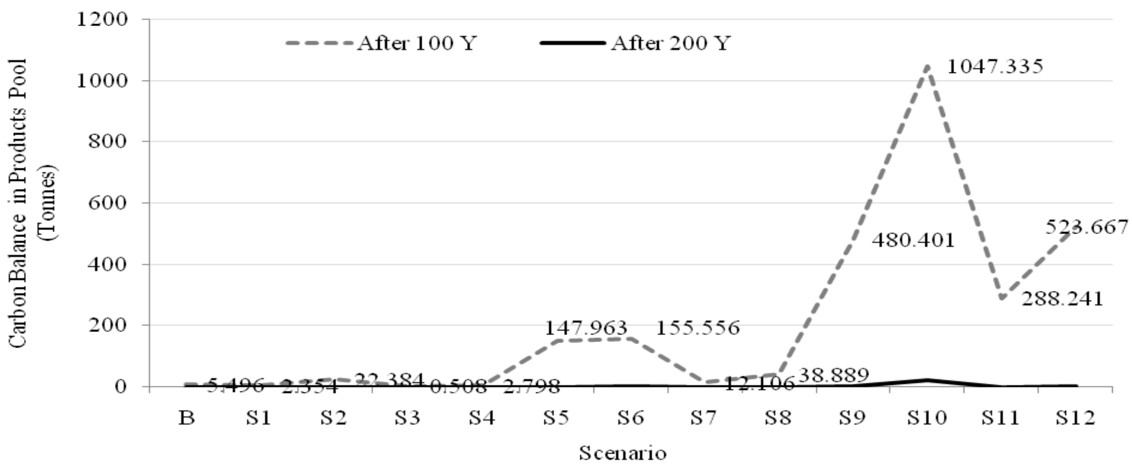

Figure 2: Carbon that remains locked in products pool in use over different scenarios.

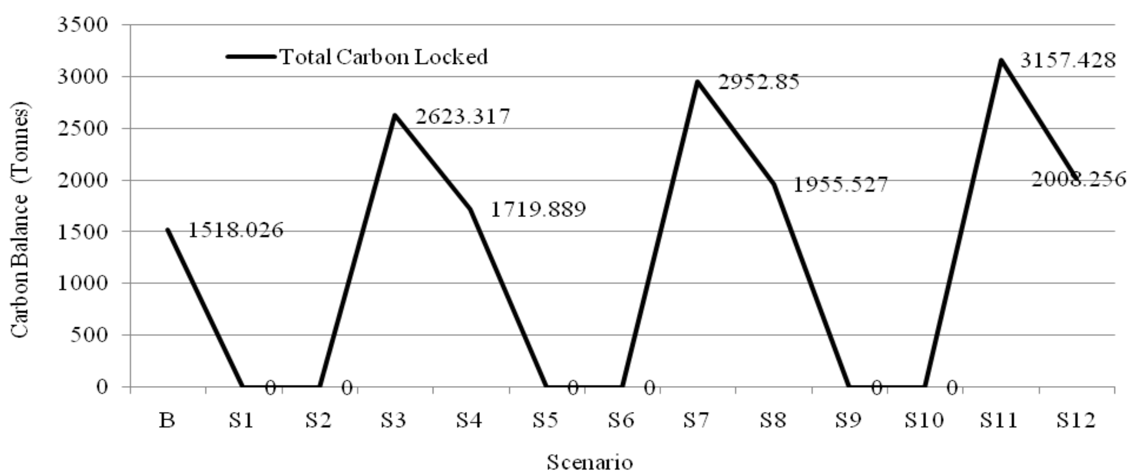

Figure 3: Total carbon that remain locked at the end of 200 years over different scenarios.

CONCLUSION

The fraction of carbon stored in harvested wood products in developing countries like India (2% in S10 scenario) is much less when compared to the carbon storage in developed countries like Finland (22% at the end of 100 years) and USA (Skog and Nicholson,1998). The analysis shows that harvested wood products can be of important stores of carbon, but only if they can store maximum extent of carbon in products pool for longer time period with right policies in place aimed at sustained harvesting cycles. Further higher percentages of carbon can be stored in harvested wood products by substituting fuel wood requirements with bio energy, by practicing innovative recycling of waste produced in the production process, by improving the manufacturing facilities, by increasing the quality of the product leading to increased products life and by recycling the products in its ultimate form before discarding into landfills . A huge amount of carbon from plants like *Dalbergia sissoo* is wasted during the process of converting the logs to products which can be improvised by adoption of proper technology. For inclusion of harvested wood products in national accounting process India needs to develop rigorous statistics on all forest productions, consumption and utilization patterns in practice that is presently absent.

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Table 3: Results of Sensitivity Analysis Summarised

Scenario	Total Carbon Remaining locked (tonnes)		Carbon locked in Products pool (tonnes)		Carbon Locked in Landfill(tonnes)		Carbon Emitted(tonnes)	
	After 100 Y	After 200 Y	After 100 Y	After 200 Y	After 100 Y	After 200 Y	After 100 Y	After 200 Y
B	1523.523	561.593	5.496	.00105	1518.026	561.592	83105.831	84072.185
S1	2.354	0.001	2.354	0.001	0	0	58178.113	58180.876
S2	22.384	0.070	22.384	0.070	0	0	31979.445	31997.604
S3	2623.825	960.343	0.508	0	2623.317	960.343	30701.568	32365.026
S4	1722.687	629.970	2.798	0.001	1719.889	629.971	30991.632	32084.107
S5	147.963	0.165	147.963	0.165	0	0	58027.060	58180.683
S6	155.556	3.333	155.556	3.333	0	0	31997.584	32123.603
S7	2964.956	1084.306	12.106	0.021	2952.850	1084.285	30360.990	32241.064
S8	1994.416	723.110	38.889	0.208	1955.527	722.902	30787.420	32055.568
S9	480.401	2.354	480.401	2.354	0	0	57616.857	58178.113
S10	1047.335	22.384	1047.335	22.384	0	0	31145.140	31979.445
S11	3445.669	1227.536	288.241	0.508	3157.428	1227.028	29893.443	32097.857
S12	2531.924	821.306	523.667	2.798	2008.256	818.508	30227.032	31893.013

- B= Business as usual scenario

[1]The common practice prevalent in India is to sell off the discarded products or use it to make other items. The wood products sold are used either for repairing works or to make other wood items.