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BIOMASS ACCOUNTING SIMULATION FOR BIOENERGY PRODUCT FROM FOREST RESOURCES

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ABSTRACT

This study examines the potential to tree component biomass, biomass for bioenergy product and sequester carbon of forest area. In order to know about these value, we used *CO2FIX program. Thinning harvesting scenario were analyzed, involving the establishment of short rotation harvesting (each 10 years) and long rotation plantations (200 year). Research results showed an overall tree* biomass *(stem, foliage, branch and root) were accounted 2.49 ton/ha±0.67, 0.14 ton/ha±0.03, 0.35 ton/ha±0.09 and 0.65 ton/ha±0.18. The potential of biomass for bioenergy product and sequester carbon was increase until the end of project simulation. The increase average biomass of bioenergy was 25.96 Mg/ha±13.46 and the average of net sequestered carbon increase about 16.6±35.9 $MgCO_2$equiv/ha. Our analysis on this study for all research variables is highest at each 40 year periods because at this age, the rate of increment in the biomass of the tree is maximized.*

KEY WORDS: Bioenergy, CO2FIX, thinning harvesting, short rotation, long rotation

INTRODUCTION

Forests provide many important ecosystem services, including wildlife habitat, recreation, soil protection, clean air and water, and timber production. As we face unprecedented global challenges in the twenty-first century, forests are also increasingly recognized for other services, including the ability to store carbon and mitigate the impacts of climate change [1] and the potential to provide bioenergy from harvest residue [2]. Today, wood energy supplies about 9 % of the worldwide demand for energy and is the single largest renewable energy source, equal to all other renewable sources combined. In addition, about 30 % of the world's population depends on wood for their primary source of energy. In the USA, wood was the sole source of human-harnessed energy until 1850 and remained the main source until coal became the primary source in the late nineteenth century [3]. Forest bioenergy has the potential to significantly reduce GHG emissions compared with fossil fuel alternatives. However, interactions between biomass harvest and forest carbon and the resulting effect on the GHG mitigation performance of bioenergy systems are inadequately understood. The potential of forest-based bioenergy to reduce greenhouse gas (GHG) emissions when displacing fossil-based energy must be balanced with forest carbon implications related to biomass harvest [4]. However, increasing harvest intensity to include biomass for bioenergy or other uses risks altering energy and nutrient cycles, soil quality, and other associated ecosystem services and attributes [5]. Wood has been an important source of energy and will continue to be for the foreseeable future. Large quantities of forest residues, including tops, limbs, cull sections, and non-merchantable round wood are potentially available for use in the production of energy, fuels, biochar, and other bioproducts, offsetting the use of fossil fuels and reducing greenhouse gas emissions [6]. Forest restoration, bioenergy production, or rehabilitation treatments involve forest thinning that can produce 40–60 million dry metric tons of woody biomass per year [7] and potential supply of biomass from forests, stems, felling residues and bark is not expected to change significantly from 2010 to 2030, but the potential from wood industry residues will increase some 30% in the same period [8]. This paper considers different approaches to calculating carbon for bioenergy that use biomass from forests that are managed with long rotations to produce multiple forest products. The objectives of this study are: (i) to provide baseline information on tree biomass component especially in stem, foliage, branch and root ; (ii) to estimate the potential of biomass for bioenergy product and sequester carbon. In order to achieve these targets, we we have used the CO2FIX program and employing various thinning harvesting scenario.

MATERIALS AND METHODS

In the present study, we have used the CO2FIX program to analysis a tree biomass components (stem, foliage, branch and root), potential of bioenergy product and net sequestered carbon in bioenergy management. The CO2FIX stand level simulation model is a tool which quantifies the C stocks and fluxes in the forest biomass, the soil organic matter and the wood products chain. The model calculates the carbon balance with a time-step of one year. Basic input is stem volume growth and allocation pattern to the other tree compartments (foliage, branches and roots) (Schelhaas et al. 2004). The model is divided in three main modules: biomass, soil organic matter and products, and runs with time-steps of 1 year. The model produces output in tabular and graphic forms. It allows estimating the time evolution of total carbon sequestered at the stand level. The total carbon stored in the forest stand at any time (CT_t) is considered to be $CT_t = Cb_t + Cs_t + Cp_t$ (t C/ha), where Cb_t is the total carbon stored in living (above plus belowground) biomass at any time t, in metric tonnes per hectare (t C/ha); Cs_t , the carbon stored in soil organic matter (t C/ha), and Cp_t is the carbon stored in wood products (t C/ha) [9]. The information on forest management practices for this study was synthesized from the literature. The dataset of management practices for model simulations consisted of product allocation for thinning harvesting and product line parameters. These kinds of information and their parameters used in CO2FIX are listed in Table 1. In this study, thinning harvesting is one of silviculture treatment scenarios that was applied every 10 years and timber harvesting in year 40, 80, 120, 160 and 200 because this is one of strategies for increasing carbon sequestration [10].

Table 1.

Summary of parameters used in simulating carbon bioenergy dynamics of tree species

Product allocation for thining harvesting [11]										
Age	Fraction removed	Log/ wood	Pulp	Slash	Log/ wood	Pulp	Slash	Foliage Slash	Firewood	Soil
3	0.50	0.70	0.00	0.3	0.00	0.00	1.00	1	0.00	1.00
10	0.6	0.70	0.00	0.3	0.00	0.00	1.00	1	0.00	1.00
20	0.5	0.70	0.00	0.3	0.00	0.00	1.00	1	0.00	1.00
30	0.25	0.70	0.00	0.3	0.00	0.00	1.00	1	0.00	1.00
40	1.00	0.70	0.00	0.3	0.00	0.00	1.00	1	0.00	1.00

Production Line Parameters [11]				
Raw Material Allocation				
	Sawn	Boards	Paper	Firewood
Logs	0.50	0.20	0.00	0.30
Pulp		0.00	0.50	0.50
Process Losses				

	Boards	Paper	FireWood	MillDump
Sawn	0.10	0.00	0.20	0.10
Boards		0.00	0.15	0.10
Paper			0.15	0.05
Firewood				0.02

End Product Parameters

Products Allocated

	Long	Medium	Short
Sawn	0.60	0.30	0.10
Boards	0.30	0.40	0.30
Paper	0.00	0.10	0.90

End of Life

	Recycling	Energy	Landfill
Long	0.05	0.80	0.15
Medium	0.05	0.80	0.15
Short	0.15	0.75	0.10

Recycling Life Span Parameters

Recycling Table

	Long	Medium	Short
Long	0.00	0.40	0.60
Medium		0.30	0.70
Short			0.00

Life Span (Years)

Long	Medium	Short	MillDump	LandFill
40	15	1	10	145

RESULTS

The potential of tree biomass components (stem, foliage, branch and root) were presented in Figure 1 and showed the similar pattern of components tree biomass. The tree biomass components tended to increase with simulating time. The increase of tree biomass was significant in stem, foliage, branch and root ($p<0.05$). Based on the results, all tree components had a biomass maximum at each 40 years, with the maximum at stem, foliage, branch and root, were accounted 2.49 ton/ha±0.67, 0.14 ton/ha±0.03, 0.35 ton/ha±0.09 and 0.65 ton/ha±0.18, respectively.

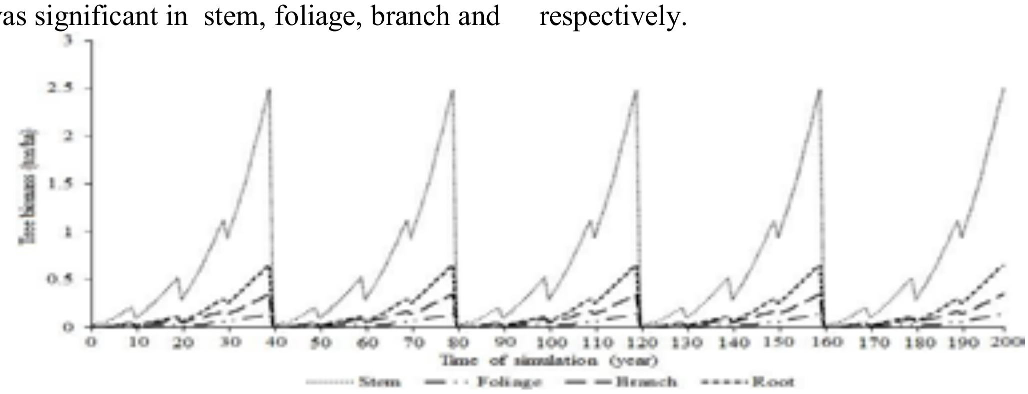

Figure 1. Tree biomass dynamics for each tree components in 200 year time simulated

In the present study, all tree biomass type increased rapidly during the simulation time of 30-40 year, 70-80 year, 110-120 year, 150-160 year and 190-200 year. This value increased from 0.94 ton/ha to 2.49 ton/ha, 0.05 ton/ha to 0.14 ton/ha, 0.14 ton/ha to 0.35 ton/ha and 0.25 ton/ha to 0.65 ton/ha for stem, foliage, branch and root, respectively. This may resulting from silviculture treatment (thinning harvesting scenario). However, on each simulated time of 0-10 year, 40-50 year, 80-90 year, 120-130 year and 160-170 year, the tree biomass of all components had the lowest biomass accumulation that comprised approximately ranging from 0.36 % (stem), 0.57 % (foliage), 0.47 % (branch) and 0.28 % (root) of the total biomass in this study, due to high thinning harvesting volume (Figure 2).

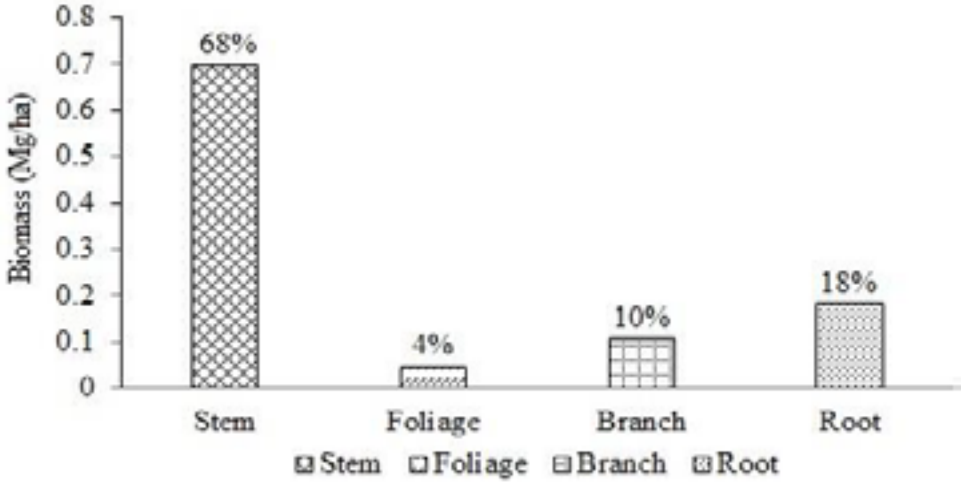

Figure 2. The averages of biomass values and percentage of tree biomass component

In Figure 3, we present the averages of biomass values and compare the percentage of each biomass component of total biomass. The biomass values and percentage of tree biomass component was vary widely from component to component. The silviculture treatments effect was statistically relevant and contribute to the total variation of the biomass tree components ($p<0.05$). The average values for each component showed differences: 0.69 Mg/ha±0.67 (68%), 0.04 Mg/ha ±0.03 (4%), 0.10 Mg/ha ±0.09 (10%) and 0.18 Mg/ha ±0.18 (18%) in stem, foliage, branch and root, respectively. The value of biomass stock for bioenergy product in this study was increased until the end of simulation period. The annual increases have varied considerably from 10 year to 10 year (statistically, it was a significant difference), ranging from as little as 3.03 Mg/ha to as much as 522.25 Mg/ha per 10 year. The increase average carbon stock of bioenergy was 25.96 Mg/ha±13.46.

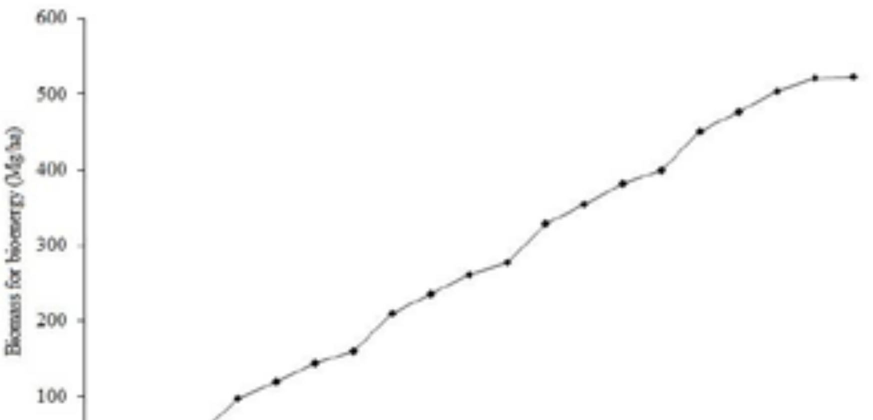

Figure 3. The potential of bioenergy product in 200 year simulation period

The potential of net sequestered carbon from the atmosphere were presented in Figure. The pattern of this variable always reach highest value in one year before silviculture treatments applied and drastically decreased when silviculture treatments (thinning harvesting) applied. This indicated an opposite relationship between thinning harvesting and net sequestered carbon in bioenergy product. Generally, the average of net sequestered carbon increase about 16.6±35.9 $MgCO_2$equiv/ha (Figure 4). The highest net sequestered carbon was found in the end of project simulation (519.41 $MgCO_2$equiv/ha).

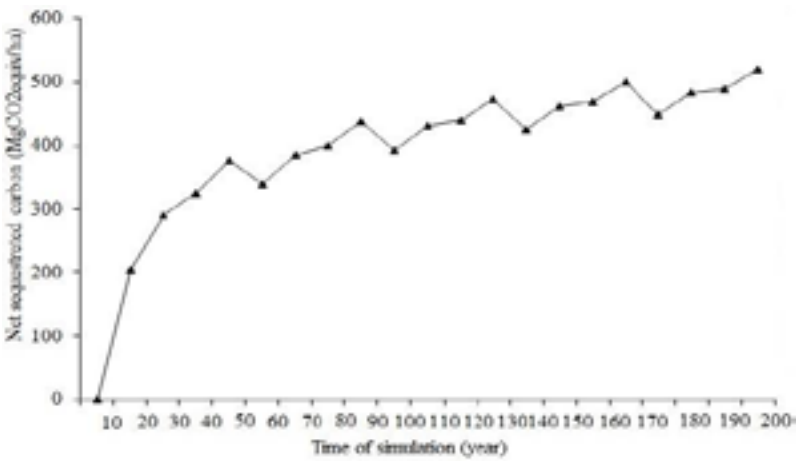

Figure 4. The potential of net sequestered carbon in bioenergy management

DISCUSSION

Based on the results, there is any strong relationship between silviculture treatment (thinning harvesting) and biomass of tree components, biomass for bioenergy production and net sequestered carbon in bioenergy management. Thinning harvesting is used to improve timber production (to obtain larger diameter and higher quality timber), but only a few data are available on how it influences tree biomass. In this study, average analysis showed that biomass stock increased by the result of the long-term thinning. The effects of thinning on biomass carbon accumulation have varied between studies [12], due to differences in thinning intensity and the length of time after thinning practice was carried out [13]. Generally, harvesting residues can be distinguished into stumps, shortcut of stems and branches. In Indonesia, on average of short-cut of stems, branches accounted for about 78% to 80% of the total residues [14]. And with the stumps in natural production forest ranged from 8.0% to 37.1%, with an average of 20.1% of the total residues, while in industrial forest plantation they ranged from 22.0% to 22.4%, with an average of 22.2% of the total residues. This implies that for every 1 m^3 produced log in natural production forest and industrial forest plantation there would be 0.351 m^3 and 0.153 m^3 harvest residues available, respectively for biomass energy. Based on productions of sawnwood, plywood, veneer sheets, chipwood and assuming the same wood specific gravity and heating value, estimates of potential bioenergy from wood processing residues for the year 2013 was about 3.60 million tons or 65.55 PJ [14]. Evergreen forests in Eastern Ghats of Tamil Nadu, India volume is 428.229 (m^3/ha), followed by deciduous 316.06 m^3/ha. Whereas secondary deciduous biomass volume of 216.673 m^3/ha, southern thorn forest with volume of 73.025 m^3/ha and euphorbia 52.72 m^3/ha. As per the estimates about 36 percent of the biomass per ha is in the form of branch and foliage, stumps and root. These are considered as sustainable source of bio-energy conversion [15]. Most of the world's biomass is in the form of woody forest materials. It is true for the developing nations; woody biomass remains the largest biomass energy source even today [16]. It is important for us to improve our knowledge about biomass composition and chemical properties, which will help us to choose appropriate technology and feed stock (Table 2). From the following table it is obvious that the tree species has the highest biomass component in meeting the energy [17].

Table 2.

Biomass Composition and Chemical Properties [16]

Biomass Component	Herbaceous (% Mass)	Poplar (Woody) (% Mass)	Pine (Woody) (% Mass)	Refuse Fuel (Waste) (% Mass)	Carbon Content (% Mass)	Higher Heating Value (MJ/Kg)
Cellulose	32	41	40	66	40-44	17
Hemicellulose	40	33	25	25	40-44	17
Lignin	4	26	35	3	63	25
Protein	12	2	1	4	53	24
Ash	5	1	1	17	0	0

Wood-based bioenergy has the potential to become a growth industry for the forest sector in a number of countries [18]. In Finland, for instance, the value of pulp and paper production was much higher in the beginning of this millennium than that of wood-based energy generation, but the difference has diminished continuously during this century's first decade. As a result, forest industries have invested in biomass-based energy generation, as well as research and development of new energy products, such as biodiesel [19]. Bioenergy or wood energy systems are complex, and involve a number of variables that have to be accounted for, including socio-economic benefits, climate change mitigation, ecological values, technological efficiency, and the interplay between industry and policy [20]. These factors explain the great variation in estimates for global forest energy resources (Table 3).

Table 3.

Global estimates of the annual forest energy potential [21]

Origin	Type of potential	Estimate (EJ)	Temporal scope	Sources
Modern fuelwood	Theoretical	379	2100	Yamamoto et al. 2001
Forest residues from industrial roundwood and fuelwood/charcoal production	Theoretical/ technical	c. 5–15	Present–2030	Berndes et al. 2003
Forest residues from industrial roundwood and fuelwood/charcoal production	Theoretical/ technical	c. 5–50	2050–2100	Berndes et al. 2003
Unspecified forest biomass	Theoretical/ technical	c. 50–100	2050	Berndes et al. 2003
Forest residues	Economic	30–150	Present–2050	IEA Bioenergy 2007
Surplus forest growth + logging residues	Theoretical	76.7	2050	Smeets & Faaij 2007
Surplus forest growth + logging residues	Technical	70.1	2050	Smeets & Faaij 2007
Surplus forest growth + logging residues	Economic	20.8	2050	Smeets & Faaij 2007
Surplus forest growth + logging residues	Economical-ecological	5.1	2050	Smeets & Faaij 2007
Primary residues	Technical	12–74	2020–2050	Nabuurs et al. 2007
Primary residues	Economic	1.2–14.8	2020–2050	Nabuurs et al. 2007

At a sub-global level, forest resources, technology, energy infrastructure, national laws and policies, and many other issues affect the use and development of the renewable energy sector. For example, the extent of wood biomass use as an energy resource varies among the European countries, and the technically available forest energy potential in the 27 European Union (EU) countries was estimated to be 1.5 EJ (36 Mtoe, or 187 million m^3) [22]. The most relevant findings of this study are that average increases the net sequestered carbon in 200-year rotation plantations by 16.6±35.9 $MgCO_2$equiv/ha. The implications of the results are that tree species in this study actually enhance carbon sequestration, are carbon sinks and store more carbon. The findings endorse the significance of thinning harvesting to increase carbon sinks and this role will broaden in the future.

CONCLUSION

Our findings support the suggestion that long-term thinning of forest in this study can improve tree biomass, biomass for bioenergy product and potential of net sequestered carbon.

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