Potential Biomass Production Estimation of Wood Energy Species in Post Mining Reclamation Area Using CO2FIX Model

F Akmalluddin*, E Sulistyawati, and Sutrisno

Forestry Engineering, School of Life Sciences & Technology, Bandung Institute of Technology, Bandung, Indonesia

*Corresponding author e-mail: akmalluddinfakhri@gmail.com

Abstract. One of the many potential uses of post-mining reclaimed land is for growing trees to use as a source of energy through their biomass. CO2FIX is a computer simulation model and can be used to estimate the production of biomass and carbon accumulation pattern of a wooden stand. The purpose of this research was to simulate biomass production of five wood energy species currently grown in the post-coal mining reclamation area at South Kalimantan, i.e. Paraserianthes falcatoria, Senna siamea, Samanea saman, Peronema canescens, and Vitex pinnata. The CO2FIX model firstly parameterized for application on the study area. The data used for parameterization gathered through literature studies and field measurements. The result indicates that the parameterized CO2FIX model could realistically simulate the growth pattern of five wood energy species grown in post-mining reclaimed land. Next, the model was used to simulate the growth of five energy wood species in the following setting: monoculture planting, 3 x 3 m planting distance, and 20 years simulation. Total of biomass in descending order shown by the stand of Senna siamea (639.35 MgDM/ha), Paraserianthes falcatoria (555.52 MgDM/ha), Samanea saman (385.77 MgDM/ha), Peronema canescens (297.71 MgDM/ha), and Vitex pinnata (219.42 MgDM/ha), respectively.

1. Introduction
One of many potential uses of post-mining reclaimed land is for growing trees to be used as a source of energy through their biomass. The utilization of biomass into bioenergy is a step to reduce the use of non-renewable fuels such as coal, oil, and gas [1]. Concerning the further utilization of biomass, it is necessary to know the productivity of a stand. One way that can be done to predict the productivity of a stand is through computer modeling. Computer modeling promises a useful method for describing the construction of relationships and the dependence of elements within it, the dynamics of existing stands, and for predicting the dynamics of stands to be built [2]. Several computer models are available to describe the dynamics of a forest stand, such as CO2FIX [3], WaNulCAS [4], SExI-FS [5], FORECAST [6], and 3PG [7]. Each of these models has particular characteristics and specifications in describing the dynamics of a stand.

One of many sites in South Kalimantan has been carried out by mining activities, and several wood stands are resulting from reclamation activities in 1997, 2014, 2015, and 2016. Some of the trees that planted here have the potential to be a source of bioenergy, such as Senna siamea, Paraserianthes falcatoria, Samanea saman, Peronema canescens, and Vitex pinnata. The advantage of these trees takes as bioenergy. Biomass productivity needs to be learned first, especially in marginal lands such as
ex-mining land. In this research, to determine biomass production of energy wood species CO2FIX simulation used. This simulation model predicts the quantification of the carbon pool and biomass dynamics of a wood stand in the ecosystem-level [3]. The CO2FIX model consists of six modules; there are biomass module, soil module, product module, bioenergy module, financial module, and carbon calculation module [8]. One of the advantages of this model is the availability of models for the bioenergy issue described in the structure of the CO2FIX model in the bioenergy module. Post mining reclaimed land have wood stand conditions that are specifics and different from other wood stands. Determination of the parameter values influence in CO2FIX model usage. In order to use CO2FIX in the post-mining reclamation site, parameterization must be done to get the desired model of the stand. The parameterized model furthermore evaluated by comparing the model's result with the actual condition, especially branch volume per hectare. This research is done to simulate biomass of five wood energy species in the post-mining reclamation site for 20 years.

2. Method

2.1. Study Area
This research located in the post-mining reclaimed land, Balangan Regency, South Kalimantan Province (Figure 1). This site has an average air temperature of 26 ° C, and annual rainfall ranges 2000-3000 mm per year [9].

In this reclamation area, there are several reclamation kinds of wood stands with different ages, including reclamation stands in 1997, 2014, 2015, and 2016. The tree species that grow on these stands include sengon (*Paraserianthes falcataria*), johar (*Senna siamea*), trembesi (*Samanea saman*), sungkai (*Peronema canescens*), and laban (*Vitex pinnata*).

![Figure 1. Location of the study area in post-mining reclaimed land, Balangan Regency, South Kalimantan](image)

2.2. Field Data Gathering
The research is done through 22 February 2019 to 1 March 2019. Data gathered from stands with different ages, with vegetation analysis method of plots 20 by 20 meters in 3 reclamation stands (planted in 1997, 2015 and 2016). Measurement is done at least three plots in each stand. Data gathered, such as plant species, diameter breast high (using measuring tape), tree height (using clinometer), and tree age (from information board in each stand).

2.3. CO2FIX Model Parameterization
In the CO2FIX model, some parameters need to be determined and filled in to describe the simulation of a particular stand. There are two components of CO2FIX model parameterization that are site condition parameterization (in soil module), and stand/species parameterization (in biomass module). In CO2FIX model the annual increase in biomass is the current biomass (stems, leaves, branches, and
roots), plus growth of biomass \((Gb_t)\) minus reduced factor, in the form of turnover \((T_t)\), mortality \((Ms_t)\), harvesting \((H_t)\), and mortality during harvesting \((Ml_t)\).

\[
Cb_{t+1} = Cb_t + Kc \left[ Gb_t - T_t - Ms_t - H_t - Ml_t \right]
\]  (1)

Growth of stand depicted through current annual increment (CAI). However, limited data about the growth of each species, making the determining process of parameterization value in a certain condition of a stand through volume table of a stand or growth data yearly, is hard to do. As an alternative, species parameterization is done through another way (equation/allometric) to know the growth of five wood energy species in post-mining reclamation stand in this location.

First, a nonlinear regression of diameter breast-high with Chapman-Richards equation and an exponential equation for tree height. The following Chapman-Richards equation:

\[
dbh (t) = dbh_{\text{max}} \times [1 - e^{-kt}]^c
\]  (2)

In general, the growth function describes changes in the size of an individual or population per unit time. In the Chapman-Richards equation, this is indicated by the time variable in the dbh calculation. \(dbh \) (t) is the tree dbh at the t-time, and \(dbh_{\text{max}}\) is the maximum dbh value that can be growth (generally the absolute value for certain species and certain site conditions). \([1 - e^{-kt}]^c\) is the dbh reduction factor in the current condition at the t-time. The parameter \(k\) is an empirical growth parameter to measure the absolute growth rate. Meanwhile, the empirical \(c\) parameter is related to catabolism (destructive metabolism), which are in the linear value of organism biomass, while the height of the tree is calculated using the dbh value of the tree, through equation (3) which illustrates the relationship between tree height and dbh of the tree. Parameter \(a\) is the coefficient of the allometric model, while parameter \(b\) is the exponent of the allometric model.

\[
h (dbh) = a (dbh)^b
\]  (3)

The data used in determining the initial values of the parameters \(c, k, \alpha, \beta\), dbh data, and dbh maximum of each species listed in Table 1. Selection of literature data related to the diameter and height of trees adjusted to the conditions in the postmining reclamation site (climate, rainfall, and temperature). Regression analysis using SPSS 21 ®, while data processing obtained from literature studies and data collection in the field was carried out using Microsoft Excel 2013 ®. Determination of the initial value of the parameter aims to make it easier when doing regression, where variations in the initial value of the parameter will produce parameter values that also vary. Therefore, it is necessary to determine the initial parameter values. Determination of the initial value of this parameter used the data normalization method with the help of Microsoft Excel 2013 ®.

After the dbh and height value is known for each species, the volume is calculated using equation (4). The \(f\) value is a correction factor of tree shape; in this equation, the \(f\) value is 0.7.

\[
V (t) = 0.25 \times 3.14 \times dbh (t)^2 \times h(dbh) \times f
\]  (4)

The final stage is the determination of CAI from the tree, which is calculated using equation (5) \(V_t\) is the wood stand volume in year \(t\), and \(V_{t-1}\) is the wood stand volume in the year before \(t\).

\[
CAI_t = V_t - V_{t-1}
\]  (5)
Table 1. Parameters, variables, definitions and data sources used for parameterization

| Parameters/Variables | Definition | Function in calculation | Initial value of the parameter and / or species data source |
|----------------------|------------|-------------------------|----------------------------------------------------------|
| c                    | Destructive metabolism | DBH | 0.844 | 2.59 | 1.607 | 0.948 | 0.948 |
| k                    | Growth rate | DBH | 0.153 | 0.161 | 0.019 | 0.014 | 0.014 |
| Dbh                  | Dbh at a certain age | Non-linear regression | [10] | [11] | [11] | [12] | [13] | [14] |
| Dbh max              | Maximum dbh | DBH | 100 cm [10] | 50 cm [15] | 200 cm [12] | 70 cm [16] | 70 cm [16] |
| Height               | Height at a certain age | Non-linear regression | [17]; [18] | [11] | [12] | [13] | [14] |
| a                    | Coefficient of the allometric model | Height | 1.33 | 1.73 | 1.26 | 2.61 | 1.14 |
| b                    | Coefficient of the allometric model | Height | 0.66 | 0.55 | 0.60 | 0.48 | 0.754 |

2.4. Simulation of the CO2FIX Model

CO2FIX model simulation was done for five wood energy species (Paraserianthes falcataria, Senna siamea, Samanea saman, Peronema canescens, and Vitex pinnata). This simulation is using a monoculture planting scheme, with 3 x 3 m distance on each plant, which means in a hectare, there are 1.111 individuals. The simulation time is 20 years. Common parameters used in this simulation listed in Table 2 and Table 3.

Table 2. Parameter values used in the modeling of five energy wood species

| Parameter                  | Nilai                  | Paraserianthes falcataria | Senna siamea | Samanea saman | Peronema canescens | Vitex pinnata | Source                      |
|----------------------------|------------------------|---------------------------|---------------|---------------|--------------------|---------------|-----------------------------|
| Carbon content             | 0.47 MgC/MgDM          |                           |               |               |                    |               | [19]                        |
| Wood density               | 0.42 g/cm3             | 0.62 g/cm3                | 0.43 g/cm3    | 0.57 g/cm3    | 0.54 g/cm3         |               | Field measurement           |
| CAI                        |                        |                           |               |               |                    |               | Use parameterization results|

Table 3. Growth relative to stems and competition (for the five species assumed to be the same)

| Value                      | Source     |
|----------------------------|------------|
| Age of wood stand 0        |            |
| Leaves                     | 1          | 1            | 0.8          |
| Branches                   | 1          | 0.6          | 0.5          |
| Roots                      | 1          | 0.8          | 0.7          | [20]          |
| Leaf turnover rate 0.5     |            |
| Branch and root turnover rate 0.05 | [20] |
| Mortality 0.01             |            |
| Biomass/Biomass Max 0      | 0.25       | 0.5          | 0.75         | 1             | [20]          |
| Growth modifier 1          | 1          | 1            | 0.75         | 0.1           |               |
3. Results and discussions

3.1. Species Parameterization Result

Diameter parameterization using the Chapman-Richards equation and height using the exponential equation is resulted in parameter value, as listed in Table 4. Highest value for $k$ and $c$ parameter are for *Peronema canescens*. The value of $k$ and $c$ in Chapman-Richards show that diameter growth on each species. $K$ is the empirical growth parameter that measures the absolute growth rate during care destructive metabolism. Based on the value of $k$ and $c$, *Senna siamea* has the fastest growth rate of dbh. Chapman-Ricards equation is a function that shows the changes in diameters on a timely basis [21].

On relation function between height and diameter, *Peronema canescens* have the highest value of parameter $a$, while *Paraserianthus falcataria* is the smallest. For parameter $b$, *Peronema canescens* have the highest value, while *Senna siamea* is the smallest. Parameter $b$ in this function has a similar function as parameter $k$ and $c$ on Chapman-Richards Equation. The value of $b$ functioned as the allometric exponent in the relation of tree's height and dbh. Therefore its influence is significant compared to the value of $a$ bigger $b$'s value, the more significant the resulting value of the equation.

| Parameters | Definition                              | Paraserianthus falcataria | Senna siamea | Samanea saman | Peronema canescens | Vitex pinnata |
|------------|----------------------------------------|---------------------------|--------------|---------------|-------------------|--------------|
| $k$        | Growth rate                            | 0.009                     | 0.202        | 0.0192        | 0.0073            | 0.0079       |
| $c$        | Catabolism                             | 0.567                     | 2.882        | 1.6076        | 0.603             | 0.71         |
| $a$        | Coefficient of the allometric model    | 1.03                      | 2.57         | 1.26          | 2.179             | 1.32         |
| $b$        | Allometric model exponent              | 0.818                     | 0.427        | 0.607         | 1.32              | 0.749        |

3.2. Tree growth

Tree growth simulation is one of the stages of parameterizing the CO2FIX model. The time of growth simulation using the Chapman-Richards equation determined for 50 years from planting. Dbh simulation data, measurement data, and literature data are combined in one graph to see whether the tree growth simulation on the post-mining reclamation area is in a realistic range according to tree growth in nature.
Simulation result using Chapman-Richards equation on parameter diameter breast height (dbh) Paraserianthes falcataria for 50 years turns out to have an inclining value, and no sign of stabilizing pattern (Figure 2a). These shows, even though it simulated for 50 years, the diameter of Paraserianthes falcataria in this location has not reached its maximum diameter. Dbh growth for Paraserianthes falcataria could reach 100 cm or even 200 cm in some cases [10]. During measurement, 20 years old Paraserianthes falcataria tree has a diameter of 20-40 cm, while three years old tree has a diameter of 5-20 cm. Simulation for 20 years of age of a tree resulted in a dbh of 38 cm, while simulation for three years of age resulted in 15 cm. These results are not much of a difference with the result of research that has bee done in the private forest of Paraserianthes falcataria in Ciamis regency, West Java Province, with a maximum diameter of 36 cm [10].

Simulation for dbh in Senna siamea for 50 years resulted in the size of dbh reached its maximum diameter at the age of 26 years (Figure 2b). This is shown in the graphic pattern that was near the dbh of 50 cm. The line does not occur to have a slight increase, but a stagnant pattern is shown instead. Senna siamea is known to have a maximum diameter of 40-50 cm [15]. The stable growth rate on dbh after nearing the maximum diameter shows that Chapman-Richards equation could represent the growth of a plant, where the graphic shows asymptote and sigmoid curves to its maximum diameter [21]. Senna siamea growth rate value on post mining reclamation site have not much of a difference from other research that has been done in Gunung Kidul [11]. Senna siamea could grow well after 2.5 years of age, it has a diameter of 2.6-3.3 cm, while in karst land habitat in Pracimantoro, Wonogiri has the diameter of 1.3-2.6 cm for the same age [11].

The simulation result of the diameter for 50 years of the Samanea saman show an increasing graphic (Figure 2c), which does not seem to show a stagnant phase. Simulation for 20 years resulted in 38 cm of dbh, which are not different from actual condition 20-60 cm. This result really like other research that has been done for this species where on a simulation of 19 years resulting in 35 cm diameter, while measurement of diameter in a mixed stand (contain Samanea saman & Enterolobium cyclocarpum) in Costa Rica, resulted in 32.9 cm of diameter for 19 years old tree of Samanea saman [22].

Peronema canescens or sungkai is one of the local species planted on this reclamation land. The result of a 50-year diameter simulation of this species shows that the graph has increased towards its maximum diameter (Figure 2d). Peronema canescens is small to moderate tree and has a maximum diameter of up to 70 cm [16].

The result of the simulation of Vitex pinnata species over 50 years shows a graph that continues to increase towards maximum dbh, even though it has not reached the maximum age of 50 years (Figure 2e). This species has a diameter that can reach 70 cm [16]. In research in the post-mining reclamation area of PT Singlurus Pratama, East Kalimantan, the average value of stem diameter at 4 years of age was 492.45 cm (123.16 cm per year) [14], whereas based on simulation results, at 4 years old it was found values of 6 cm for diameter and 5 m for height. This shows the least difference between the simulation results and the real conditions in the post-mining reclamation area.

3.3. Comparison of Simulation Results with Actual Conditions
The CO2FIX model simulation uses the results of characterization results at the same time (age) and the number of individuals as the stand conditions in the field. This model presents simulation outputs in tabular and graphical form (specific output values displayed in the table). In the table view, the output presented includes biomass and carbon (stems, branches, leaves, and roots), stem/hectare volume, CAI, total standing biomass and carbon, and carbon from the atmosphere absorbed.

The parameter value approach used in the simulation model needs to be tested or evaluated. The evaluation process is done by comparing the actual conditions with the output of the simulation model, which is the volume component of stems per hectare. The results of a comparison between the actual conditions with the simulation model can be seen in Table 5.
Table 5. Comparison of simulation results with actual conditions

| Wood stand                        | Number of trees (N/ha) | Actual Age | Volume (m$^3$/ha) | Simulation Age | Volume (m$^3$/ha) |
|-----------------------------------|------------------------|------------|-------------------|----------------|------------------|
| Paraserianthes falcataria         | 220                    | 3 Year     | 19.83             | 3 Year         | 16.75            |
| Senna siamea                      | 534                    | 4 Year     | 12.56             | 4 Year         | 16.83            |
| Samanea saman                     | 217                    | 20 Year    | 183.14            | 20 Year        | 181.95           |
| Peronema canescens                | 160                    | 20 Year    | 68.88             | 20 Year        | 64.12            |
| Vitex pinnata                     | 225                    | 20 Year    | 37.96             | 20 Year        | 34.20            |

Based on these results, it can be seen that the largest difference between the simulation results with the actual condition is in the *Senna siamea* stand, which is 4.27 m$^3$, and the smallest difference is in the *Samanea saman* stand with a value of 1.19 m$^3$. *Senna siamea* or johar stands were the dominant plants in reclamation land in 2015 (four years), this can be seen in the results table that *Senna siamea* stand has a tree density of 534 in one hectare. A large number of individuals also influence the comparison between actual conditions and the model, because the more number of species, the more variations in diameter and height values are components in the calculation of volume.

In *Samanea saman* stand there is a small difference between the model and the actual conditions, because of the measurement results of stands aged 20 years, the average *Samanea saman* has a diameter of 35.2 cm while in the simulation results obtained a diameter value at the age of 20 years of 36.75 cm. The difference in value between the actual conditions and the simulation results ranging from 1.19 - 4.27 m$^3$ shows that there is not too much difference between the actual conditions and the results of the parameterization model so that the results of the parameterization can be used in the model.

3.4. Biomass Simulation of Five Stands of Wood Energy

The CO2FIX model divides biomass into several components, such as stem, leaf, root, and branch biomass. The graph of the simulation results can be seen in Figure 3. Simulations for 20 years on the *Vitex pinnata* stand show that all components of the biomass contained in the stand continue to increase (Figure 3a). Total biomass experienced a slow increase from the beginning of planting to the fourth year and after that, experienced a significant increase until the 20th year. In the 20th year, it estimated that total biomass, stem biomass, leaf biomass, twig biomass, and root biomass contained in the *Vitex pinnata* stand respectively 219.42 MgDM/ha, 102.08 MgDM/ha, 16.57 MgDM/ha, 43.02 MgDM/ha, and 57.75 MgDM/ha. In the *Peronema canescens* stand the total biomass simulation results show a large increase graph and then experience a not so large increase after reaching the 16th year (Figure 3b). In the 20th year it estimated that total biomass, stem biomass, leaf biomass, twig biomass, and root biomass *Peronema canescens* stands are 297.71 MgDM/ha, 141.97 MgDM/ha, 19.37 MgDM/ha, 58.66 MgDM/ha, and 77.71 MgDM/ha.

The biomass simulation in the *Samanea saman* stand shows a similar pattern to the *Peronema canescens* stand. At the beginning of planting until the fourth year, the amount of biomass experienced a tiny increase, then after that experienced a significant increase until the 18th year, where the graph shows a stagnant pattern until the end of the simulation (Figure 3c). The leaf biomass graph has not increased in the ninth year. In the 20th year, it estimated that the total biomass, stem biomass, leaf biomass, twig biomass, and branch biomass contained in the *Samanea saman* stand are respectively 385.77 MgDM/ha, 184.05 MgDM/ha, 23.79 MgDM/ha, 76.06 MgDM/ha, and 101.87 MgDM/ha.

In the stand of *Senna Siamea*, the simulation, which conducted for 20 years, showed a graphic pattern that had increased very rapidly from the fourth year to the eighth year. After that, there was a stagnant chart pattern and decreased until the 20th year (Figure 3d). In the leaf component, the decline in the value of biomass occurs in the seventh to the 16th year and then experiences a stagnant graph pattern. The decline in the value of biomass can occur if the biomass in the stand has reached its
maximum value. When a stand has reached the maximum biomass, the competition within the stand will increase. In the CO2FIX model, the very tight competition defined as the value/index of competition whose value is close to one (no growth occurs) [3]. When growth does not occur, then the death of mature trees will continue so that the biomass in the stand is even less. In the 20th year, it estimated that the total biomass, stem biomass, leaf biomass, branch biomass and root biomass contained in the *Senna siamea* stand are respectively 639.35 MgDM/Ha, 320.42 MgDM/ha, 29.8 MgDM/ha, 126.51 MgDM/ha, and 162.62 MgDM/ha.

Figure 3. Biomass simulation using CO2FIX, (a) *Vitex pinnata*; (b) *Peronema canescens*; (c) *Samanea saman*; (d) *Senna siamea*; (e) *Paraserianthes falcataria*

Stand biomass of *Paraserianthes falcataria* in simulation for 20 years has a similar pattern with biomass growth in *Senna siamea* stand pattern. In the 20th year, it estimated that the total biomass, stem biomass, leaf biomass, branch biomass, and root biomass contained in the *Paraserianthes falcataria* stands respectively 555.52 MgDM/Ha, 278.36 MgDM/ha, 25.24 MgDM/ha, 110.08 MgDM/ha, dan 141.84 MgDM/ha (Figure 3e). Based on the results of the 20th year biomass simulation, *Senna siamea* is the largest total biomass stand compared to the other four stands. This is due to the excellent adaptability of this species so that it can grow even in dry and nutrient-poor soil conditions. This adaptability causes rapid growth so that in the simulation component, the diameter of *Senna siamea* can have a significant change in value from the fourth to the 19th year and reaches the maximum diameter in the 20th year.

4. Conclusion

The conclusions obtained based on the results of this study are: (1) Parameterization of the model can simulate realistic growth for five energy wood species on this study area, such as *Senna siamea*, *Paraserianthes falcataria*, *Samanea saman*, *Peronema canescens*, and *Vitex pinnata*, (2) The CO2FIX simulation stem volume values using parameterization results are not much different from the actual conditions in the field, (3) The result shows that in 20th year, the total of biomass in descending order shown by the stand of *Senna siamea* (639.35 MgDM/ha), *Paraserianthes falcataria* (555.52 MgDM/ha), *Samanea saman* (385.77 MgDM/ha), *Peronema canescens* (297.71 MgDM/ha), and *Vitex pinnata* (219.42 MgDM/ha).
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