Joint production of wood, resin, and carbon from pine plantation forest in Java

Y Indrajaya

Forestry Research and Development Institute for Agroforestry Technology, Jl. Raya Ciamis-Banjarmasin km 4, Ciamis, Indonesia

email : yonky_indrajaya@yahoo.com

Abstract. Pine (Pinus merkusii) plantation forest has been developed in Java Island under Perhutani management with clear-cutting and artificial regeneration silviculture system. The main products of pine plantation forests are wood and resin. Although the Indonesian government has committed to reduce the greenhouse gases (GHGs) emission for 26% by 2020 with voluntary efforts, pine plantation forest may contribute to reduce GHGs emission through enhancing carbon stock. The additional income from carbon sales might or might not change the optimal rotation of the pine forest. This study aims to analyze the effects of additional income from resin and carbon benefits on the optimal rotation of pine plantation forest in Java. The modified Faustmann model is used to determine the optimal rotation. The results of this study show that (1) the inclusion of resin benefits may lengthen the optimal rotation age, (2) the optimal rotation of timber and resin production of pine forest in Java for size class III, IV, V, and VI are 34, 33, 32, and 30 years respectively, (3) additional income from carbon sales may increase carbon stock by 8%, and lengthen optimal rotation for 3 years. Perhutani may change the optimal rotation due to additional benefits from resin and carbon.

1. Introduction

Pine (Pinus merkusii) plantation forest has been developed in Java Island under state owned company (i.e. Perum Perhutani) management with clear-cutting and artificial regeneration silviculture system. The main products of pine plantation forests in designated production forest area are wood and resin, while in designated protected areas are wood, resin, and ecotourism. Total area of pine forest managed by Perum Perhutani in Java is 163,150 ha [1] that produced resin for 83,059 ton in 2016.

The decision on pine forest rotation is based on maximum yield approach where the forest will be clear cut and replanted when the mean annual increment is the same as current annual increment. Foresters commonly use this maximum yield approach for determining optimal rotation of a monoculture forest. However, this approach may give no maximum profit from the economic perspective. Samuelson [2] argued that the correct approach for determining optimal forest rotation to obtain maximum profit is by using Faustmann formula when wood is the only product from the forest. The Faustmann formula has been applied in determining optimal rotation in many countries in the world. Hartman [3] proposes an approach for determining optimal rotation when non-timber forest products are considered as additional revenues. Researches on the effects of non-timber forest products on optimal forest rotation have been conducted particularly for pine forest. Additional
income from resin sales lengthen rotation age of pine forest in China [4], while additional revenue from carbon sales may lengthen optimal rotation [5, 6].

The Government of Indonesia (GoI) have committed to reduce greenhouse gases (GHG) for 26% voluntarily without international support and 41% with international support [7]. One of the sectors that may contribute to this commitment is Land Use, Land Use Change, and Forestry (LULUCF) through several activities: avoiding deforestation, avoiding forest fire (including peatland management), conservation & rehabilitation, and increasing carbon stocks. Plantation forest may also contribute to climate change mitigation by reforestation, afforestation and increasing carbon stocks by lengthening harvest rotation [8]. The inclusion of carbon sales in profit maximization problem in forestry has been discussed in the forest economics literature. In afforestation project under Clean Development Mechanism (CDM), additional revenue from carbon sales will lengthen the rotation age [9, 10]. Carbon price affects the length of the postponing harvest due to higher opportunity cost of not harvesting.

This study aims to analyze the effects of additional income from resin and carbon benefits simultaneously to optimal rotation of pine plantation forest in Java. The analysis includes different site conditions for pine plantation that influences the tree growth. Carbon price effects will also be analyzed to give more understanding on how carbon prices would give effects on optimal pine plantation.

2. Method

The method used in this study is modified Faustmann model, where the forest manager will maximize Net Present Value (NPV) in infinite horizons. The NPV of the pine forest where wood is the only product is as it follows:

\[ NPV_w = \frac{p_w V_T - E(1+i)^T}{(1+i)^T-1} \]  

\( p_w \) refers to wood price (IDR/m³), \( V_T \) represents stumpage volume (m³) at rotation year \( T \), \( K \) is plantation cost \(^1\), and \( i \) is interest rate \(^2\). The wood prices, timber volumes and plantation cost are assumed to be constant over rotation period. The wood prices depend on the size of the wood, where the larger the size, the higher the price will be. The wood prices used are as those as they are predicted by Prasetyo, Saleh and Soedomo [11]:

\[ p_w = 200948 \ln t - 181909 \]  

\( p_w \) is the timber price (IDR/m³). The stumpage volume is estimated based on normal table of Suharlan, Sumarna and Sudiono [13]. The volume and diameter estimation in the normal table of Suharlan, Sumarna and Sudiono [13] are presented in a 5-year growth period. To be more precise, growth models are developed to estimate every year growth, following Indrajaya [14], i.e.:

\[ \ln D_t = \alpha - \beta / t; \ln V_t = \alpha - \beta / t \]  

\(^1\) Total plantation costs per ha are IDR 5,776,291 consisting of planning; planting; maintenance and forest development; fire control & forest protection; cost fulfilment financial obligations to the state, environment & social; maintenance of facilities and infrastructure; cutting wood, employee, management; general & administrative; others [11] Prasetyo A R, Saleh M B and Soedomo S 2017 Optimization Pine Plantation Forest Management in Kediri FMU Regional Division II East Java Jurnal Manajemen Hutan Tropika 23 171-81.

\(^2\) The interest rate used in this study is 4% as the average real interest rate in Indonesia over 20 years is about 4% [12] World Bank 2016 World Bank Development Indicator. In: 1960-2015, ed W Bank.
The values of $\alpha$ and $\beta$ predicted are presented in Table 1.

**Table 1.** The values of $\alpha$ and $\beta$ for estimating volume and diameter of pine tree

| Site class  | $\alpha$  | Volume  |
|------------|-----------|---------|
| III        | 4.144     | 6.131   |
| IV         | 4.281     | 6.131   |
| V          | 4.375     | 6.136   |
| VI         | 4.555     | 6.123   |

Following Wang, Calderon and Carandang [4], resin is assumed to be produced by pine tree with diameter breast height (DBH) > 20 cm and only 300 trees/ha are tapped for resin production. According to volume table of Suherlan et al. (1975), the 20 cm DBH of pine trees are reached at year 10 for all site classes. It is also assumed that resin is produced every day along the whole year (i.e. 365 days in a year). Therefore, following Prasetyo, Saleh and Soedomo [11], the resin production function is as it follows:

$$R_t = [(5.98 + 0.36t - 0.007t^2) \times 300 \times 365]/1000$$

(4)

Where $R_t$ is the production of resin (kg/ha) in year $t$. The NPV of resin production from pine plantation forest is as it follows:

$$NPV_t = \frac{\sum_{t=10}^T R_t (1+i)^{T-1}}{(1+i)^{T-1}}$$

(5)

$p_r$ is the price of resin (IDR/kg)$^3$ and $R$ represents the resin production (kg/ha). The NPV from carbon sales is the total amount of carbon that is sold in the market. Total amount of carbon stored in forest biomass was estimated with the following estimations. The weight of above ground forest biomass is estimated from the volume of tree and biomass expansion factor:

$$AGT_t = V_t \times \rho \times BEF$$

(6)

$AGT_t$ refers to the above ground biomass at year $t$ (ton/ha), $V_t$ represents the wood volume (m$^3$/ha), $\rho$ is the wood density$^4$ of pine and $BEF$ is the biomass expansion factor$^5$.

The weight of root biomass is estimated by allometric equation of Cairns, Brown, Helmer and Baumgardner [18], i.e.:

---

$^3$ The resin price used in this study is IDR 3457/kg based on [15] Ministry of Trade 2012 Peraturan Menteri Perdagangan RI No 22/M-DAG/PER/4/2012. Ministry of Trade of Republic Indonesia

$^4$ The wood density of pine is 0.53[16] Zanne A E, Lopez-Gonzalez, G.* C, D.A., Ilic J, Jansen, S., Lewis S L, Miller R B, Swenson N G, Wiemann M C and Chave J 2009 Global wood density database

$^5$ The value of BEF for pine trees is 1.33 [17] Krisnawati H, Adinggroho W and Imanuddin R 2012 Monograf model-model alometrik untuk pendugaan biomassa pohon pada berbagai tipe ekosistem hutan di Indonesia Pusat Penelitian dan Pengembangan Konservasi dan Rehabilitasi, Badan Litbang Kehutanan, Bogor-Indonesia
\[
RB_t = \exp(\alpha + \beta \ln AGB_t)
\]

\(RB_t\) refers to the weight of root biomass \((\text{ton/ha})\). If the fraction of carbon in tree biomass is 0.47 \[19\] and the ratio of \(\text{CO}_2\) and \(\text{C}\) are \(44/12\), therefore, total amount of \(\text{CO}_2\) stored in tree biomass is \(TB = (AGB_t + RB_t) \times 0.47 \times 44/12\). The baselines used in this study is the average amount of carbon stored in tree biomass at the optimal rotation age with wood and resin production:

\[
BB_t = \frac{1}{T} \sum_{t=1}^{T} TB_t
\]

For all \(t\) such that \(BB_t < TB_t = \frac{1}{T} \sum_{t=1}^{T} TB_t\)

(9)

Where \(BB_t\) is the baseline emission for site class \(s\). The NPV of carbon sales is as it follows:

\[
NPV_c = \frac{\sum_{t=1}^{T} p_c C(1+i)^{-t-1}}{(1+i)^{-1}}
\]

(10)

Where \(p_c\) is the carbon price per ton \(\text{CO}_2\). The carbon price used is in the range of 0-50 USD/ton \(\text{CO}_2\)\(^6\). Total NPV of joint production of wood, resin and carbon is therefore:

\[
NPV_{w,r,c} = NPV_w + NPV_r + NPV_c
\]

(11)

3. Results and Discussion

3.1. Optimal Rotation with Wood Production Only

In general, the wood production is larger in pine forest with higher site class. Site class represents the suitability of site with certain species. The more suitable the site, the fastest the growth will be. In the case of pine forest in Java, the fastest growth is for site class VI where the mean annual increment (MAI) may reach 16.1 m\(^3\)/year at year 11 (see Figure 1). In contrary, the MAI of pine forest for site class III is only 9.9 m\(^3\)/year at year 15. Traditional foresters commonly determine optimal forest rotation using maximum sustained yield (MSY) where the forest will be clear-cut when MAI = CAI (current annual increment).

Optimal rotation with Maximum Sustained Yield (MSY) for site class III, IV, V, and VI are 18, 14, 13 and 11 respectively. Economists criticize the approach of MSY and argue that MSY may give not optimal rotation age. The NPVs of pine plantation forest when only timber as the source of income are presented in Table 2. The optimal rotation age for site class III, IV, V and VI are 27, 25, 24, and 23. The faster the growth of pine forest, the shorter of optimal financial rotation will be. The highest NPV is achieved at site class VI (i.e. IDR 46,919,791) that is the most suitable site for pine trees.

\(\text{World Bank Development Indicator. In: 1960-2015, ed W Bank}\)

---

\(^{6}\) The exchange rate used in this study is exchange rate in 2016 i.e. USD 1= IDR 13,380 \[12\] World Bank 2016 World Bank Development Indicator. In: 1960-2015, ed W Bank
3.2. Optimal Rotation of Joint Production of Wood and Resin

Pine trees do not only produce wood for many purposes but also resin for rosin and turpentine[20] which are important as industrial chemicals. Rosin is raw material for adhesives, paper sizing agents, printing inks, detergents, etc. [21]. Turpentine is widely used for varnishes, perfume, disinfectants, cleaning agents, and others [21]. The production of resin in Java is presented in Figure 2.

Figure 2 shows that wood volume of pine forest still increases until year 50 but with lower increment. However, resin production reaches its peak production at year 26 with 1,162 kg/ha and then would decrease to 710 kg/ha at year 50. The optimal rotation of pine forest with the inclusion of resin production lengthens, i.e.: 34, 33, 32, and 30 for site class III, IV, V, and VI respectively (Table 3). Postponing wood harvest from its Faustmann rotation (wood production only) to produce more resin until the additional income from resin decrease is an important decision for forest manager in determining optimal forest rotation. With additional income from resin, the optimal rotation of pine forest lengthens for about 7-8 years. Perhutani has set the rotation of pine forest with wood and resin production of 35 year [22] that is slightly longer than the optimal rotation calculated in this study. This result is similar to those studied by Wang, Calderon and Carandang [4] and Prasetyo, Saleh and Soedomo [11] that additional benefit from resin may lengthen the rotation age. However, this finding is different from the finding of Andayani [22] that the inclusion of resin may shorten the rotation period under normal forest analysis.
Figure 2. Wood and resin production of pine forest in Java

The NPV of joint production of wood and resin are more than double for all site classes. Because the resin production is assumed to be the same for all site classes, lower site class will be obtained larger proportion of additional benefit from resin production. The NPV of site class III increases from IDR 34,901,554 to 85,996,537 (146%); while the NPV of site class VI only increases from IDR 46,919,791 to 94,731,121 (102%).

Table 3. NPV of joint production of wood and resin of pine forest in Java

| Rotation (year) | Site Class III | Site Class IV | Site Class V | Site Class VI |
|-----------------|----------------|---------------|--------------|---------------|
| 28              | 83,914,632     | 87,870,006    | 91,129,157   | 94,408,938    |
| 29              | 84,601,235     | 88,399,506    | 91,528,600   | 94,639,778    |
| 30              | 85,134,369     | 88,778,918    | 91,781,315   | 94,731,121    |
| 31              | 85,528,145     | 89,022,811    | 91,902,129   | 94,697,767    |
| 32              | 85,795,434     | 89,144,393    | 91,904,433   | 94,553,007    |
| 33              | 85,947,987     | 89,155,656    | 91,800,330   | 94,308,799    |
| 34              | **85,996,537** | 89,067,491    | 91,600,774   | 93,975,913    |
| 35              | 85,950,892     | 88,889,799    | 91,315,686   | 93,564,060    |
| 36              | 85,820,018     | 88,631,589    | 90,954,057   | 93,082,007    |

3.3. Carbon Sequestration

Pine forest may absorb and store carbon in its biomass through a photosynthesis process. The amount of carbon stored in tree biomass of pine forest at its optimal rotation is presented in Figure 3. As the current management in pine forest in Java focuses on the wood and resin products, the baseline for carbon project is the average amount of carbon stored in tree biomass at its optimal rotation, i.e.: 34, 33, 32, and 30 year for site class III, IV, V, and VI respectively. The baseline for site class III, IV, V, and VI are 202, 212, 220, and 223 respectively.
Figure 3. Carbon dynamics of pine forest on site class III-VI

3.4. Joint Production of Wood, Resin, and Carbon

The NPV of joint production of wood, resin, and carbon at carbon price 5, 10, and 30 USD/ton CO$_2$ are presented in Table 4-6. Additional income from carbon sales changes the optimal rotation of pine forest. At carbon price of 5 USD/ton CO$_2$, the optimal rotation on site class III, IV, V and VI are 37, 36, 35, and 33 year (about 3 years longer than the baseline). However, the NPV is slightly higher than those in baseline (i.e. joint production of wood and resin). Table 5 and 6 show that the higher carbon price may give larger effect on postponing the harvest because the value living stumpage trees become larger.

### Table 4. NPV of joint production of wood, resin, and carbon at carbon price 5 USD/ton CO$_2$

| Rotation (year) | Site Class III | Site Class IV | Site Class V | Site Class VI |
|----------------|----------------|---------------|--------------|--------------|
| 32             | 85,795,434     | 89,144,393    | 91,904,433   | 95,298,196   |
| 33             | 85,947,987     | 89,155,656    | 92,132,792   | **95,386,418** |
| 34             | 85,996,537     | 89,067,491    | 92,234,558   | 95,367,074   |
| 35             | 86,228,213     | 89,196,122    | **92,234,564** | 95,250,262   |
| 36             | 86,368,663     | **89,216,488** | 92,143,190   | 95,036,878   |
| 37             | **86,401,008** | 89,139,469    | 91,964,191   | 94,747,468   |
| 38             | 86,358,633     | 88,995,882    | 91,707,111   | 94,390,334   |
Table 5. NPV of joint production of wood, resin, and carbon at carbon price 10 USD/ton CO$_2$

| Rotation (year) | Site Class III | Site Class IV | Site Class V | Site Class VI |
|----------------|----------------|---------------|--------------|--------------|
| 35             | 86,505,534     | 89,502,445    | 93,153,443   | 96,936,464   |
| 36             | 86,917,309     | 89,801,386    | 93,332,324   | 96,991,750   |
| 37             | 87,189,901     | 89,977,878    | 93,304,336   | 96,957,266   |
| 38             | 87,382,578     | 90,086,085    | 93,381,162   | 96,842,453   |
| 39             | 87,474,282     | **90,097,732**| 93,281,733   | 96,652,968   |
| 40             | 87,474,282     | 90,030,910    | 93,113,733   | 96,382,607   |
| 41             | 87,437,038     | 89,898,360    | 92,866,851   | 96,056,025   |

Table 6. NPV of joint production of wood, resin, and carbon at carbon price 30 USD/ton CO$_2$

| Rotation (year) | Site Class III | Site Class IV | Site Class V | Site Class VI |
|----------------|----------------|---------------|--------------|--------------|
| 46             | 96,159,945     | 98,909,854    | 103,477,322  | 109,546,915  |
| 47             | 96,366,244     | 99,075,418    | 103,553,505  | 109,579,840  |
| 48             | 96,505,697     | 99,190,714    | 103,551,752  | 109,529,337  |
| 49             | 96,579,112     | **99,235,876**| 103,502,547  | 109,441,155  |
| 50             | **96,611,988** | 99,227,876    | 103,417,320  | 109,319,314  |

4. Conclusions
Additional revenues from non-wood forest product may change the optimal rotation of pine plantation forest. The results of this study show that: (1) the inclusion of resin benefits may lengthen the optimal rotation age, (2) the optimal rotation of timber and resin production of pine forest in Java for site class III, IV, V, and VI are 34, 33, 32, and 30 years respectively, (3) additional income from carbon sales at carbon price 5 USD/ton CO$_2$ may increase carbon stock by 8%, and lengthen optimal rotation for 3 years; (4) The higher the price of carbon may give larger effects on postponing the harvest because the value of living stumpage trees becomes larger.

References
[1] Perum Perhutani 2016 Annual Report 2016, Changing the Work Culture Strengthening the Business.
[2] Samuelson P A 2012 Economics of forestry in an evolving society Journal of Natural Resources Policy Research 173-95.
[3] Hartman R 1976 Harvesting decision when a standing forest has value Econ Inq 14 52-8.
[4] Wang Z, Calderon M M and Carandang M G 2006 Effects of resin tapping on optimal rotation age of pine plantation Journal of forest economics 11 245-60.
[5] Manley B and Maclaren P 2012 Potential impact of carbon trading on forest management in New Zealand Forest Policy and Economics 24 35-40.
[6] Huang C-H and Kronrad G D 2006 The effect of carbon revenues on the rotation and profitability of loblolly pine plantations in East Texas Southern Journal of Applied Forestry 30 21-9.
[7] Sekretariat Kabinet Republik Indonesia 2011 Peraturan Presiden Nomor 61 Tahun 2011 tentang Rencana Aksi Nasional Penurunan Emisi Gas Rumah Kaca. ed J Setkab RI (Jakarta).
[8] Richards K R and Stokes C 2004 A review of forest carbon sequestration cost studies: a dozen years of research Climatic change 63 1-48.
[9] Galinato G I and Uchida S 2011 The effect of temporary certified emission reductions on forest rotations and carbon supply Canadian Journal of Agricultural Economics/Revue canadienne d’agroeconomie59 145-64.

[10] Olschewski R and Benitez P C 2010 Optimizing joint production of timber and carbon sequestration of afforestation projects Journal of Forest Economics 16 1-10.

[11] Prasetyo A R, Saleh M B and Soedomo S 2017 Optimization Fine Plantation Forest Management in Kediri FMU Regional Division II East Java Jurnal Manajemen Hutan Tropika23 171-8.1

[12] World Bank 2016 World Bank Development Indicator. In: 1960-2015, ed W Bank.

[13] Suharlan A, Sumarna K and Sudiono J 1975 Tabel Tegakan Sepuluh Jenis Kayu Industri (Bogor: Pusat Penelitian dan Pengembangan Hutan).

[14] Indrajaya Y 2016 Manfaat lingkungan penyerapan karbon hutan pinus pada beberapa kelas tempat tumbuh di Jawa. In: Seminar Nasional Geografi UMS 2016, ed Priyono, et al. (Surakarta: Universitas Muhamadiyah Surakarta).

[15] Ministry of Trade 2012 Peraturan Menteri Perdagangan RI No 22/M-DAG/PER/4/2012. Ministry of Trade of Republic Indonesia).

[16] Zanne A E, Lopez-Gonzalez, G.* C, D.A., Ilic J, Jansen, S., Lewis S L, Miller R B, Swenson N G, Wiemann M C and Chave J 2009 Global wood density database.

[17] Krisnawati H, Adinugroho W and Imanuddin R 2012 Monograf model-model alometrik untuk pendugaan biomass pohon pada berbagai tipe ekosistem hutan di Indonesia Pusat Penelitian dan Pengembangan Konservasi dan Rehabilitasi, Badan Litbang Kehutanan, Bogor-Indonesia.

[18] Cairns M A, Brown S, Helmer E H and Baumgardner G A 1997 Root biomass allocation in the world’s upland forests Oecologia111 1-11.

[19] IPCC 2006 IPCC Guideline 2006 Guidelines for national green house gas inventories. IPCC).

[20] Zinkel D F 2018 Organic chemicals from biomass: CRC Press) pp 163-87.

[21] Coppen J J W and Hone G A 1995 Gum naval stores: Turpentine and rosin from pine resin. In: Non-wood forest products 2., (Rome, Italy: Food and Agriculture Organization).

[22] Andayani W 2006 Analisis Keuntungan Pengusahaan Hutan Pinus (Pinus Merkusii Jung Et De Vriese) Di KPH Pekalongan Barat (The Pine (Pinus merkusii Jung et de Vriese) Forest Plantation Rentability Analysis In KPH West Pekalongan) Jurnal Manajemen Hutan Tropika12.