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Estimation of Potential Carbon Economic Value of Bamboo In Community Forest Area in Rumpin-Dalam Hamlet, Rumpin Village, Bogor District

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ABSTRACT

Community forests represented one area that could be utilized in carbon trading. Rumpin-Dalam Hamlet had an area in the form of a community forest with a bamboo forest formation. The planned construction of the Serpong-Bogor toll road could result in the loss of part of the bamboo forest. This study aimed to determine the potential of bamboo, biomass, absorption, and economic value of carbon in the bamboo forest. The research procedure began with the determination and placement of plots in the bamboo forest. Biomass data collection occurred in a non-destructive manner (without causing damage). The next step was to calculate biomass, carbon stock, carbon sequestration, and the carbon economic value. The research results showed that there were five types of bamboo in the Rumpin-Dalam Hamlet Community Forest. These types included apus bamboo (*Gigantochloa apus*), mayan bamboo (*Gigantochloa robusta*), black bamboo (*Gigantochloa atroviolacea*), ater bamboo (*Gigantochloa atter*), and betung bamboo (*Dendrocalamus asper*). Bamboo forests in the area absorbed a carbon potential of 403.55 tCO_2 and had a carbon economic value of US$ 20,177.5.

Keywords: Bamboo, Carbon, Carbon Economic Value, Community Forests, Rumpin Village

1. Introduction

Global warming is a problem that is increasingly experienced and felt by all people in the world. This is marked by rising temperatures and uncertainty in global climate conditions. Global warming comes from various human activities starting from the burning of fossil fuels, industry, and large-scale deforestation which of course causes carbon emissions with the impacts, namely the greenhouse effect which also has long-term effects on life, and is required to reduce activities that can damage forests or activities that can cause emissions [1].

Forests are able to absorb carbon dioxide in the atmosphere through the process of photosynthesis. Carbon dioxide is absorbed and stored as carbon reserves in tree body. The entire body of a tree is called biomass, which stores carbon. The continuous process of photosynthesis increases the size of the biomass and carbon reserves in the tree body [2].

The potential of bamboo in Indonesia is very large, besides having various species, it also has a large area of bamboo forest. Indonesia has approximately 10% of the species of bamboo that grow in the world and are found in lowlands to mountains with altitudes between 0-2,000 meters above sea level. Currently, the species of bamboo that have been identified worldwide are more than 1,300 species and are included in 107 genera [3].

Rumpin Village, which has an area of 639 Ha, is one of the bamboo-producing villages in Bogor Regency. Bamboo plants have great ecological benefits. Bamboo can be a solution to environmental threats and the impacts of climate change. Bamboo plays an important role in land restoration through the adaptability of its plant species, landscape approach, and its existence in a sustainable ecosystem [4].

This study is based on the Rumpin-Dalam Hamlet community forest which has the potential of bamboo as an environmental service in the form of a carbon sequestration. Meanwhile, according to circulating information, the Bogor-Serpong toll road project will eliminate most of them. Thus, this study will describe the value of the loss of potential economic carbon in the community forests.

2. Research Method

2.1. Research Area

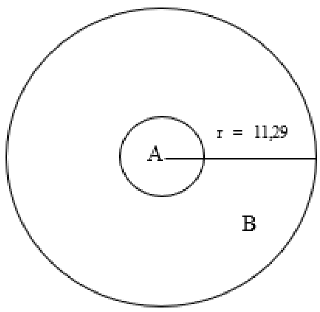
This research was conducted in October 2024 and took place in Rumpin-Dalam Hamlet community forest. The bamboo forest studied has an area of 60 ha.

2.2. Procedures

2.2.1. Determination of Observation Plots

The observation plot is determined based on the Regulation of the Minister of Forestry Number P.67/Menhut-II/2006 (Permenhut 67/2006) concerning Forest Inventory Criteria and Standards, which states that the Sampling Intensity (SI) for bamboo is at least 0.05%. The SI in this study was taken as 2% of the total area, so the area of the observation plot was 1.2 ha.

The measurement plot uses a circle method with an area of 0.04 Ha [5] so the number of plots is 30 (Figure 1). Plot placement was done purposefully, considering the ideal proportions of bamboo species distribution.



Where:

A : Sub Plot Size 4 m^2 for litter

B : Sub Plot Size 400 m^2 for Bamboo Plants

Figure 1. Data Collection Plot

2.2.2. Bamboo Biomass Data Collection

Bamboo biomass measurements were conducted using non-destructive methods. This method does not require cutting bamboo samples, but instead uses an allometric formula. Each bamboo clump's diameter was measured at diameter breast high-DBH (1.3 meters).

2.2.3. Litter Biomass Data Collection

Litter biomass sampling was carried out in 30 plots each measuring 4 m^2. After that, the total wet weight of the litter in the 4 m^2 plot was weighed. After that, a test sample of 300 g/plot was taken and then dried using an oven at a temperature of 105°C until a constant weight was obtained [5].

2.3. Data analysis

2.3.1. Potential of Standing Trees

The calculation of the potential of this stand consists of: the average number of culms per clump, the number of clumps per hectare, and the number of culms per hectare as follows [3]:

a) Calculating the average number of culms per clump (*Y'*)

$$Y' = \frac{\Sigma Y}{\Sigma X} \quad (1)$$

b) Calculating the average number of culms per plot (*Y''*)

$$Y'' = \frac{\Sigma Y}{\Sigma CP} \quad (2)$$

c) Count amount average cluster per plot (*X'*)

$$X' = \frac{\Sigma X}{\Sigma CP} \quad (3)$$

d) Calculating the number of clumps per hectare (*X''*)

$$X'' = \frac{X'}{(\frac{LCP}{10.000})} \quad (4)$$

e) Calculating the number of culms per hectare (*Y'''*)

$$Y''' = \frac{Y''}{(\frac{LCP}{10.000})} \quad (5)$$

Where:

Y	:	Number of plot bars
Y'	:	Average number of culms per clump
Y''	:	Average number of culms per plot
Y'''	:	Average number of culms per hectare
X	:	Number of clusters
X'	:	Number of clumps per plot
X''	:	Average number of clumps per hectare
CP	:	Number of sample plots
LCP	:	Area of sample plot

2.3.2. Biomass Calculation

2.3.2.1. Bamboo Biomass Calculation

Calculation of Bamboo biomass using an allometric model in estimating biomass and carbon reserves using DBH at breast height (1.3 m). Each bamboo clump is measured 10 bamboo culms randomly to obtain the average diameter of the bamboo clump. Based on research conducted by [6]. allometric formulas for various types of bamboo are determined based on the diameter of the culms.

Table 1. Allometric Equations

Bamboo	Allometric equations
Bamboo apus (*Gigantochloa apus*)	$W = 0.9802\ D^{1.3984}$
Bamboo ater (*Gigantochloa atter*)	$W = 1.0668\ D^{1.3539}$
Bamboo betung (*Dendrocalamus asper*)	$W = 1.2974\ D^{1.3512}$

Information: W = Bamboo biomass (kg), D = diameter (cm)

Bamboo species whose allometric have not been discovered are assumed to use the following general bamboo allometric formula [7]:

$$W = a\ D^{b} \quad (6)$$

$$W = 0.131\ D^{2.62} \quad (7)$$

Where:

W : Bamboo biomass (kg)
D : Diameter of bamboo at breast height (cm)
ab : Estimation coefficient

2.3.2.2. Litter Biomass Calculation

Litter sampling assumes that there is no difference in the type of bamboo litter to estimate litter biomass. Litter biomass can be done by calculating the total dry weight using the following formula according to [5].

$$Boss = (Bks \times Bbt)/Bbs \quad (8)$$

Where:

Boss : weight of organic litter material, expressed in kilograms (kg)
Bks : dry weight of the sample, expressed in kilograms (kg)
Bbt : total wet weight, expressed in kilograms (kg)
Bbs : wet weight of sample, expressed in (kg).

2.3.3. Carbon Stock Calculation

Calculation of carbon stock is obtained from biomass using the following formula.

$$C = B \times \% \text{ organic } C \quad (9)$$

Where :

C	:	The carbon content of biomass (kg)
B	:	Total biomass (kg)
% C organic	:	The percentage value of carbon content (47% / 0.47)

2.3.4. Carbon Sequestration Calculation

Calculation of carbon dioxide absorption according to [8] is calculated based on the mass comparison of the photosynthesis reaction equation:

$$\underset{(264)}{6CO_2} + \underset{(108)}{6H_2O} \longrightarrow \underset{(180)}{C_6H_{12}O_6} + \underset{(192)}{6\,O_2} \quad (10)$$

Based on the photosynthesis reaction equation above, to produce 180 grams of biomass ($C_6H_{12}O_6$) approximately 264 grams of CO_2 are required, therefore CO_2 absorption can be determined using the formula:

$$\text{Carbon sequestration} = 264/180 \times \text{Biomass} = 1{,}4667 \times \text{Biomass} \quad (11)$$

2.3.5. Carbon Economic Value

The carbon economic value (CEV) is calculated using *Social Cost of Carbon* according to *the Environmental Defense Fund.* The set carbon price is US$50 per ton [9]. The CEV can be calculated using the following approach [10]:

$$\text{CEV} = \text{Carbon price (per ton)} \times \text{Carbon Sequestration} \quad (12)$$

3. Result and Discussion

3.1. Bamboo Potential

The research results showed that there were five types of bamboo in the Rumpin-Dalam Hamlet Community Forest. These types included apus bamboo (*Gigantochloa apus*), mayan bamboo (*Gigantochloa robusta*), black bamboo (*Gigantochloa atroviolacea*), ater bamboo (*Gigantochloa atter*), and betung bamboo (*Dendrocalamus asper*).

Table 2. Bamboo Potential in Rumpin-Dalam Hamlet Community Forest

No	Bamboo	Culm diameter (cm)	Clump/ha	Total Clump	Bamboo culm/ha	Total bamboo culm
1	Apus bamboo (*Gigantochloa apus*)	5.02	154	9,250	2,844	170,650
2	Mayan bamboo (*Gigantochloa robusta)*	8.34	41	2,450	370	22,200
3	Black bamboo (*Gigantochloa atroviolacea)*	4.80	45	2,700	769	46,150
4	Ater bamboo (*Gigantochloa atter)*	7.70	10	600	67	4,000
5	Betung bamboo (*Dendrocalamus asper)*	10.4	14	850	296	17,735
			264	15,850	4,346	260,735

Bamboo dominates the area, this is influenced by several ecological and economic factors. Ecologically, bamboo has a high adaptability to various soil type. In addition, bamboo can grow in areas with moderate to high rainfall. In line with [11]. said that bamboo growth is closely related to the influence of environmental conditions where bamboo grows. Bamboo is economically useful, both as building materials, crafts, and daily needs. The Rumpin Village community tends to cultivate bamboo compared to other species of plants because the rapid bamboo growth cycle. This is reinforced by research by [4] which states that most people in Rumpin Village depend on bamboo for their daily household needs and school fees.

Figure 2. Bamboo Types in Rumpin-Dalam Hamlet Community Forest

3.2. Biomass

Biomass was material derived from living things, including organic materials both living and dead, both above ground level and below ground level, such as trees, crops, grass, litter, and roots [12]. The total biomass potential are 1,235.92 tons, consisting of bamboo (275.14 tons) and litter (960.78 tons).

Table 3. Biomass Potential in Rumpin-Dalam Hamlet Community Forest

No	Bamboo	Biomass (tons/ha)	Total Biomass (tons)
1	Apus bamboo (*Gigantochloa apus*)	1.74	104.62
2	Mayan bamboo (*Gigantochloa robusta)*	0.53	31.53
3	Black bamboo (*Gigantochloa atroviolacea)*	0.20	12.13
4	Ater bamboo (*Gigantochloa atter)*	0.45	26.83
5	Betung bamboo (*Dendrocalamus asper)*	1.67	100.04
6	Litter	16.01	960.78
	Total	20.60	1,235.92

The largest biomass content in the bamboo forest (Table 3) is produced by apus bamboo, which is 104.62 tons. The smallest biomass is produced by black bamboo, which is 12.13 tons. These results show variations in biomass storage capacity between species, which are influenced by population factors, while when viewed from morphological factors such as culm diameter, the largest biomass content is found in bamboo that has a large diameter (such as betung bamboo). It tends to have a higher biomass potential, so it is one of the species that are effective in absorbing carbon. According to allometric formula [5], the size of a plant's biomass is directly proportional to its carbon stores. This is reinforced by the statement of [7] that plant biomass is closely correlated with carbon sequestration capacity.

3.3. Carbon Stock

The estimated total carbon stock value is 580.88 tons. The largest carbon stock potential (besides litter) is in the apus bamboo with a total of 0.82 tons/ha, and the smallest carbon stock potential is in the black bamboo with 0.10 tons/ha (Table 4).

Table 4. Carbon Stock in Rumpin-Dalam Hamlet Community Forest

No	Bamboo	Carbon stock (tons/ha)	Total Carbon Stock (tons)
1	Apus bamboo (*Gigantochloa apus*)	0.82	49.17
2	Mayan bamboo (*Gigantochloa robusta)*	0.25	14.82
3	Black bamboo (*Gigantochloa atroviolacea)*	0.10	5.70
4	Ater bamboo (*Gigantochloa atter)*	0.21	12.61
5	Betung bamboo (*Dendrocalamus asper)*	0.78	47.02
6	Litter	7.53	451.57
	Total	9.68	580.88

The largest biomass content in the bamboo forest (Table 3) is produced by apus bamboo, which is 104.62 tons. The smallest biomass is produced by black bamboo, which is 12.13 tons. These results show variations in biomass storage capacity between species, which are influenced by population factors, while when viewed from morphological factors such as culm diameter, the largest biomass content is found in bamboo that has a large diameter (such as betung bamboo). It tends to have a higher biomass potential, so it is one of the species that are effective in absorbing carbon. According to allometric formula [5], the size of a plant's biomass is directly proportional to its carbon stores. This is reinforced by the statement of [7] that plant biomass is closely correlated with carbon sequestration capacity.

The carbon stock in bamboo is relatively high because bamboo has growth characteristics that allow cutting several reeds in one clump without removing all of its carbon stock. This is in accordance with the statement from [13] that bamboo only needs to be planted once and when it reaches the age of 3-5 years it can be harvested every year without having to be replanted.

3.4. Carbon sequestration

The potential for carbon sequestration is estimated at 403.55 tons. Apus bamboo has the largest potential (2.56 tons/ha), meanwhile the black bamboo type is the smallest one (Table 5).

Table 5. Carbon Sequestration in Rumpin-Dalam Hamlet Community Forest

No	Bamboo	Carbon sequestration (tons/ha)	Total Carbon Sequestration (tons)
1	Apus bamboo (*Gigantochloa apus*)	2.56	153.44
2	Mayan bamboo (*Gigantochloa robusta)*	0.77	46.24
3	Black bamboo (*Gigantochloa atroviolacea)*	0.30	17.79
4	Ater bamboo (*Gigantochloa atter)*	0.66	39.36
5	Betung bamboo (*Dendrocalamus asper)*	2.45	146.72
	Total	6.73	403.55

The growth rate of bamboo as one of the plants has the potential to mitigate GHG effects. However, the carbon stock capacity of bamboo tends to be lower compared to woody plants, due to the lower biomass content. On the other hand, woody plants have a greater biomass potential so they can store carbon in greater amounts in the long term. This statement is in accordance with [14] that bamboo produces oxygen 30% faster than trees which can help reduce carbon dioxide. Bamboo has a high ability to absorb carbon dioxide, so it can absorb carbon dioxide in the Rumpin-Dalam Hamlet Community Forest reaching 403.55 tCO_2.

3.5. Carbon Economic Value

Indonesia's carbon emission reduction strategy through FOLU Net Sink 2030 targets a reduction in GHG emissions of -140 million tons of CO_2e by 2030 [15]. The bamboo forest in Rumpin-Dalam Hamlet can contribute to the carbon emission reduction plan with a 60 ha bamboo forest capable of absorbing 403.55 tCO_2 of carbon (equal to US$ 20,177.5). The calculation is based on the social cost value. Bamboo was used by the Rumpin village community as their primary livelihood. Due to the planned construction of the Serpong-Bogor toll road, which has the potential to reduce some of the bamboo forest, a social cost scheme is appropriate. According to [16], the social cost of carbon is used to estimate the economic value of carbon for environmental damage that occurs.

The part of bamboo forest in Rumpin Village will be affected by the construction of the Serpong-Bogor toll road. There has been an agreement between the community and the developer stating that the community has agreed to the loss of part of the area [17]. Thus, there is a chance that the bamboo forest will be affected by the construction of the toll road which will cause damage or loss of the bamboo forest area. Land loss in bamboo ecosystems has the potential to reduce the area's contribution as a provider of environmental services, especially in terms of carbon absorption.

Presidential Regulation No. 98 of 2021 (Perpres 98/2021) defines carbon trading as a market-based mechanism to reduce GHG emissions through the buying and selling of Carbon Units, so it can be concluded that carbon trading in Indonesia has the potential to maintain forest and environmental conservation by achieving carbon emission reduction targets. In line with [18] that the carbon tax functions as a tax instrument used to correct social costs arising from negative externalities due to environmental pollution. Carbon trading policies can encourage forest conservation and restoration efforts as absorbers and stores of large amounts of carbon reserves. Carbon potential can be converted into credits in carbon trading. According to [19], imposing a carbon tax can be used as a fairly effective mitigation measure in reducing carbon and greenhouse gas emissions.

The carbon trading scheme refers to the voluntary carbon market and the mandatory carbon market. The voluntary carbon market was formed due to the desire to reduce GHG emissions with mechanisms that are not regulated by the government (mechanisms are developed by stakeholders). The mandatory market was formed due to regulations to reduce or limit the amount of GHG emissions released [20]. Based on this mechanism, it can be concluded that the community forest area of Rumpin village can be categorized as a voluntary carbon market because the legal ownership of the land is held by the private sector. However, the government can utilize it to fulfill the FoLU Net Sink 2030 program in terms of reducing GHG emissions.

4. Conclusion

The Rumpin-Dalam Hamlet community forest has the potential for apus bamboo (*Gigantochloa apus*) with a total of 154 clumps (2844 culms) per hectare, mayan bamboo (*Gigantochloa robusta*) with a total of 41 clumps (370 culms) per hectare, black bamboo (*Gigantochloa atroviolacea*) with a total of 45 clumps (370 culms) per hectare, ater bamboo (*Gigantochloa atter*) with a total of 10 clumps (67 culms) per hectare, and betung bamboo (*Dendrocalamus asper*) with 14 clumps (296 culms) per hectare. Estimated carbon sequestration is 403.55 tCO_2e, equal to US$ 20,177.5.

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