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RESEARCH ARTICLE

The Estimation of Economic Valuation on Carbon Sequestration of Agroforestry Land System

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ABSTRACT

The role of Perhutani and local farmers in developing agroforestry in Bogor Forest Management Unit (FMU) is important for carbon sequestration-based climate mitigation efforts. Different compositions of the plants in seven agroforestry systems in four part of Bogor FMU. Farmers adjust the multipurpose crops planted with Perhutani main plants, which are more dominant. The potential mean annual carbon increment based on aboveground carbon stock of agroforestry is between 2.26 to 66.65 tonnes per hectare, while in 2 monocultures land system is between 13.65 to 18.29 tonnes per hectare. The carbon increment in agroforestry systems is better than monoculture because of plant diversity and different ages. Then, carbon revenue using carbon pricing set by the World Bank-FCPF Program in East Kalimantan is in the range of IDR 1,547,325 to IDR 49,292,405 per hectare, using the Social Cost scheme in the range IDR 12,997,535 to IDR 414,056,204 per hectare and using domestic carbon tax is range IDR 635.017 to IDR 20,229,441 per-hectare. Regarding carbon revenues, the wider the agroforestry land managed by farmers, the higher the carbon income received. Using the benefit transfer method over a 20-year mitigation period, an estimated 2.19 times increase in carbon revenues is obtained at an inflation rate of 4%.

Introduction

The increase in human activities that produce Greenhouse gases (GHGs) emissions into the atmosphere is one of the causes of the increase in temperature on the earth's surface. The source GHG emissions are classified into five categories: energy, industry and product use, agriculture, forestry and other land uses, and waste management [1]. To achieve the 2030 greenhouse gas emissions reduction target, various climate mitigation efforts must be endeavored [2]. Climate change mitigation in Indonesia is defined in the Minister of Energy and Mineral Resources Regulation No. 22 of 2019, Article 1, point 12, as an effort intended to reduce the amount of GHG emissions to minimize the impact of climate change. There are two main sectors of climate change mitigation in Indonesia the forestry sector as a source of carbon absorption and the energy sector as a source of GHG emissions, which must be reduced [3]. Mitigation of reducing emissions in the forestry sector and land use does not only use UNFCCC compliance mechanisms but also the idea of payment for ecosystem services (PES), that is forest and land carbon sequestration [4]. Efforts to sequester carbon (carbon sinks) include sustainable forest management, prevention of deforestation and forest degradation, illegal logging, prevention of forest and land fires, and forest and land rehabilitation.

Indonesia is the third largest producer of greenhouse gases due to land use change and deforestation [5]. Forest cover continues to decline to less than 15% of the total forest area in Java due to land conversion [6]. Therefore, Perum Perhutani, as a state corporation that manages forest areas in Java, focuses on forest management, reforestation, and prevention of deforestation. One of the areas managed by Perum Perhutani is the Bogor Forest Management Unit (FMU), which has an area of 49,337.06 hectares (ha), of which 88.16% is timber production forest. Bogor FMU consists of 5 parts of the forest management unit (PFMU) namely, Parung panjang, Jonggol, Jasinga-Leuwiliang, Bogor and Ujung Krawang. However, currently timber

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production is only carried out at Parung-panjang PFMU, because the geographical conditions of the other PFMU have wavy to steep topography which is prone to landslides. On the other hand, population growth along with the development of tourism in Bogor Regency has resulted in reduced forest cover, which is estimated to be 15,665.79 ha [7]. Also, the temperature in Puncak-Bogor Area increased by 0.61 degrees Celsius during 2010–2020 [8]. Conversely, Bogor FMU also establishes an agroforestry system partnership, where the community can utilize forest through empowering forest village communities. It is now called by the Indonesian Government the Social Forestry program. This aims to improve social welfare, reduce land tenure conflicts, and create sustainable forests. Therefore, research must be carried out at Bogor FMU to rehabilitate community-based forests while supporting carbon emission reduction.

Agroforestry is an environmentally friendly land resource management approach applied by most farmers worldwide. Agroforestry systems may accomplish both goals, i.e., to mitigate climate change while improving food security and the local economy by reducing unemployment [9,10]. Agroforestry generates large profits in the long term but also has big challenges, such as large initial capital and high maintenance costs, so losses are often encountered in the early years. Uncertainty about profits, gravest time, and lack of capital caused agroforestry scope to be small and became a consideration for farmers in choosing agroforestry or monoculture cropping patterns [11–13]. Among the advantages and challenges of agroforestry, agroforestry has a big role in absorbing carbon and soil fertility and increasing land productivity [14,15]. Then, the benefits of carbon sequestration on agroforestry land are social and economic value, which is potential for climate financing and carbon trading [16]. This value is represented as the net present value of preventing damage to the world in the future (up to 100 years or more) by reducing or preventing additional CO_2 emissions at a certain time, which is manifested in carbon prices [17]. Carbon trading is possible domestically or internationally with Perhutani as a seller of carbon credits to parties who need to reduce their emission targets. In fact, the value of agroforestry carbon in Bogor FMU has never been carried out, even though it has the potential to increase income through sharing of carbon sales between Bogor FMU and farmers.

Theoretically, the more carbon accumulated in farmer's agroforestry, the greater the potential for annual carbon payments [18,19], because of farmers' participation in REDD+ (Reducing Emission from Forest Degradation and Deforestation), goes into their household income [19–21]. The objective of this research is to determine the implementation of the agroforestry system in Bogor FMU and estimates carbon economic value from carbon reserved contained in agroforestry plants, which are equivalent to the absorption of carbon dioxide emissions.

Material and Methods

Study Area

The research was conducted in 4 parts of Bogor Forest Management Unit, namely Parung-panjang PFMU, Jonggol PFMU, Jasinga-Leuwiliang PFMU and Bogor PFMU which have an active agroforestry land system shown on Figure 1. This research location is in Bogor Regency, West Java Province. Agroforestry is one of the Bogor FMU business unit that makes social contributions, including efforts to resolve tenure conflicts. The Research was carried out in March and April 2023.

Data Collection Method

The research use an quantitative method. Quantitative methods are used to analyze the diversity of vegetation on carbon stocks, and the economic value of carbon as a potential farmer's additional income. Primary data is collected by field measurement to calculate aboveground biomass according to SNI 7724:2011 - ground based forest carbon accounting, to determine the biomass in agroforestry land samples. For undergrowth, biomass and carbon stock is estimated by laboratory analysis to calculate dry weight and wet weight. Sample selection of carbon measurement plots using a purposive sampling technique of 7 plots representing the entire area of the Bogor FMU. Secondary data is collected by literature studies regarding the prevailing carbon price reference.

Data Analysis Method

Importance Value Index and Diversity

The data processing method in this study is a quantitative method. To determine the diversity of plant species and plant composition in the study area, the importance value index and Shannon-Wener diversity index were measured in 7 sample plots measuring 20 x 20 m. The plots also represent the types of plants grown in the 23 agroforestry samples belonging to the sample farmers. The important value index formula [22], as follows:

$$Relative\ Density = \frac{one\ species\ density}{sum\ of\ all\ species\ density} \times 100\% \quad (1)$$

$$Relative\ Frequency = \frac{Frequency\ of\ one\ species}{sum\ of\ all\ species'\ frequency} \times 100\% \quad (2)$$

$$Relative\ Dominance = \frac{Dominance\ of\ one\ species}{Dominance\ of\ all\ species} \times 100\% \quad (3)$$

$$Importance\ Value\ Index\ (IVI) = Relative\ Density + Relative\ Frequency + Relative\ Dominance \quad (4)$$

To determine the level of diversity of plant species using the Shannon-Wener diversity index [23]. The value of H' < 1 indicates low species diversity, 1<H'<3 indicates moderate species diversity and H' > 3 indicates high species diversity with the following formula:

$$H' = \sum_{i=1}^{s} \frac{n_i}{N} \ln \frac{n_i}{N} \quad (5)$$

Where:

H' : Shannon-Wiener Diversity Index

S : Sum of all number of species

n_i : i^{th} Density

N : Sum of Density

Estimated Carbon Store Between Monoculture and Agroforestry System

Aboveground biomass is calculated according to the type of vegetation, using allometric equations and using tree dimension data that obtained [24]. Biomass is measured using a non-destructive method. This method is a measurement that is carried out without damaging the part of the plant which was measured. This method can be used if the formula for calculating the biomass or the allometric formula for the plant species to be measured is known [1,25]. The allometric equation for the plants planted by 23 samples of agroforestry farmers in the Bogor FMU can be seen in Table 1.

Table 1. Allometric equation for measuring biomass of plants in the research location.

No.	Trees	Allometric equation	Source
1	Teak	$B = 0.015 \times (D^2H)^{1.08}$	Hairiah et al. [26]
2	Coffee	$B = 0.281 \times (D)^{2.06}$	Hairiah et al. [26]
3	Mahogany	$B = 0.902 \times ((D^2H)^{0.08}$	Badriyah & Purwanto [27]
4	Pine	$B = 0.206 \times \rho \times D^{2.26}$	Hairiah et al. [26]
5	Acacia	$B = 0.077 \times (D^2H)^{0.90}$	Choirudin & Purwanto[28]
6	African wood	$B = 0.0363 \times D^{2.5151}$	Hairiah et al. [26]
7	Branched tree	$B = 0.11 \times \rho \times D^{2.62}$	Ketterings et al. [29]
	Unbranched tree	$B = \pi \times \rho \times \left(\frac{D^2H}{40}\right)$	Hairiah et al. [26]

B: Biomass, D: diameter, H: height.

The formula used is that the carbon stored is 47% of the stored biomass while the carbon absorption is 3.67 times that of the stored carbon stock [30]. The assessment of the criteria for estimating carbon stocks uses an approach that values agroforestry carbon stocks [27], i.e., bad criteria if the range of carbon stocks is < 30 Mg H^{-1}, sufficient if carbon stocks are around 30 to 70 Mg H^{-1}, good if carbon stocks are in the range of 70 to 110 Mg H^{-1} and very good if carbon stocks are > 110 Mg H^{-1}. Meanwhile, the annual carbon increment formula is the total carbon stock divided by the age of the plant [31].

Estimation of Carbon Economic Value During Mitigation

Income derived from agroforestry's carbon sequestration is calculated using 3 carbon prices because the carbon value can be traded on domestic to international carbon markets. Potential buyers in carbon market-based instruments vary widely, both internationally and domestically [32]. So far, Indonesian carbon buyers come from foreign parties, but due to weak demand, Indonesia has focused more on developing the domestic carbon market as a policy tool to achieve the unconditional Nationally Determined Contribution target. The first, based on carbon pricing used in the Forest Carbon Partnership Facility (FCPF) Program - World Bank Carbon Fund in East Kalimantan Province is USD 5/tCO_2e or worth IDR 73,100/tCO_2e. Second, based on the value of Social Cost or social costs set by developed countries for carbon emissions released from the industrial sector, one of which is the US government, which sets USD 42/tCO_2e [33] or IDR 614,040/tCO_2e. Third, the domestic carbon price based on Indonesian law (*Undang - Undang Nomor 7 Tahun 2021 tentang Harmonisasi Peraturan Perpajakan* / UU HPP) stipulates the lowest carbon tax price of IDR 30,000/tCO_2e. This tax is set for business sector that do not achieve emission reduction targets, which can be used to increase carbon absorption through forest rehabilitation activity, such as agroforestry. Then, benefit transfer method is used to determine the value of carbon absorption revenue in 2043 according to the 20-year climate change mitigation period with the following formula [34,35]:

$$V = (1 + i)^t P \tag{6}$$

Where:

V : Carbon revenue in 2043 (IDR)

I : Average inflation rate (%)

P : Carbon revenue in 2023 (IDR)

T : Climate mitigation period which is 20 years from 2023–2043

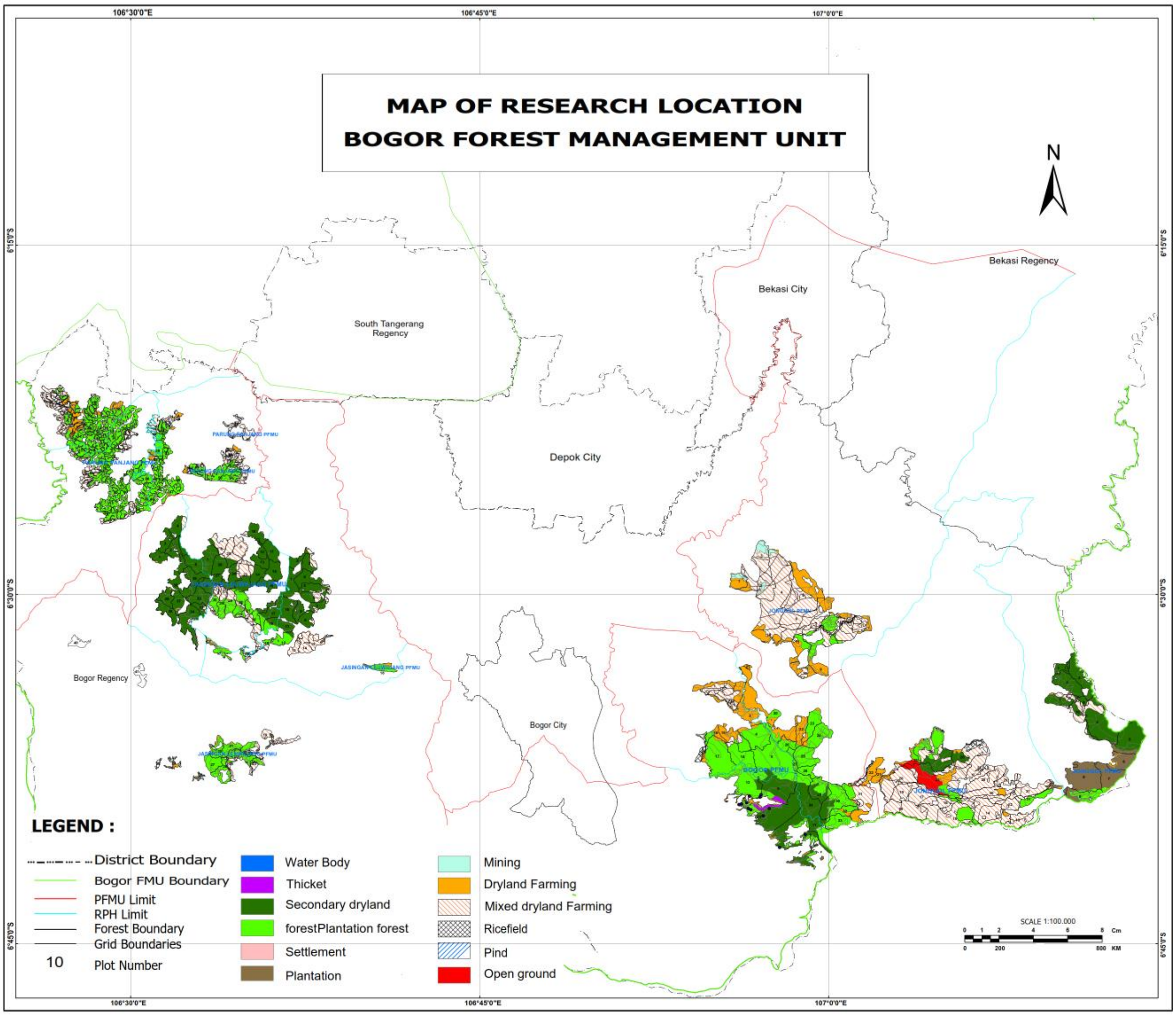

Figure 1. Research location in Bogor Forest Management Unit.

Results and Discussion

Plant Composition in The Research Location

Land management system in the research area uses 2 systems, monoculture and agroforestry. The monoculture forests chosen were meranti forest at Jasinga-Leuwiliang PFMU and mahogany forest at Parung Panjang PFMU. While the agroforestry management system studied seven samples from four PFMU. The results of the analysis of the composition of agroforestry plants are shown in Table 2.

Table 2. The composition and diversity index of agroforestry plants in the research location.

No.	PFMU	Name	Vegetation group	Relative density	Relative frequency	Relative dominance	IVI
1	Parung panjang	Teak	Sapling and Pole	73.65	33.33	95.89	202.88
		Mahogany	Sapling	4.19	16.67	4.11	24.97
		Papaya	Lower plants	0.60	16.67	-	17.27
		Sorgum	Lower plants	19.16	16.67	-	35.83
		Galangal	Lower plants	2.40	16.67	-	19.06
Shannon-Wiener Diversity Index in Parung Panjang PFMU = 0.79							
2	Jonggol	Acacia	Tree	85.45	16.67	99.80	201.92
		Avocado	Sapling	7.27	16.67	0.18	24.12
		Durian	Sapling	1.82	16.67	0.01	18.50
		Papaya	Lower plants	1.82	16.67	-	18.48
		Lime	Lower plants	1.82	16.67	-	18.48
		Banana	Lower plants	1.82	16.67	-	18.48
Shannon-Wiener Diversity Index in Jonggol PFMU = 0.62							
3	Jasinga-Leuwiliang	Durian	Tree	22.39	12.50	95.98	130.87
		Mango	Tree	25.37	12.50	4.02	41.89
		Pine	Sapling and pole	50.75	12.50	12.07	75.32
		Coffee	Sapling	1.49	12.50	0.03	14.02
Shannon-Wiener Diversity Index in Jasinga-Leuwiliang PFMU = 1.09							
4	Bogor	Clove	Sapling and pole	15.00	6.25	2.93	24.18
		Durian	Sapling	17.50	3.13	1.03	21.65
		Pine	Tree	18.75	6.25	57.75	82.75
		African Wood	Tree	5.00	6.25	15.20	26.45
		Coffee	Sapling and pole	28.75	6.25	8.72	43.72
		Avocado	Tree	2.50	3.13	3.12	8.74
		Petai	Tree and sapling	2.50	3.13	2.13	7.76
		Gadog	Tree	1.25	3.13	1.70	6.07
		Damar	Sapling	1.25	3.13	0.19	4.56
		Guava	Sapling	1.25	3.13	0.18	4.55
		Suren	Tree	2.50	3.13	2.93	8.56
		Jackfruit	Tree	3.75	3.13	4.13	11.00
Shannon-Wiener Diversity Index in Bogor PFMU = 1.98							

IVI: importance index value

The composition of agroforestry plants in the four PFMUs is unlike each other. Each research area in PFMU has a different main timber plant, Parung Panjang PFMU is dominated by teak, Jonggol PFMU is dominated by acacia, Jasinga-Leuwiliang PFMU is dominated by pine and durian. In contrast, Bogor PFMU is dominated by pine. The highest plant diversity was at Bogor PFMU, with a value of 1.98, which was planted by 11 different agroforestry plants. The lowest plant diversity in Jonggol PFMU means that the planting of seasonal crops is less varied and is still dominated by Perhutani's main timber plants. This means that main timber plants are still more dominant in each plot observed, meaning that agroforestry farmers do not use the land optimally for intercrops or multipurpose tree species that could potentially develop. Agroforestry system in Parung Panjang PFMU is planted with Perhutani's main timber-plant i.e., teak and undergrowth plants such as sorghum and galangal. At Jonggol PFMU, the multipurpose plants planted are fruit trees. Meanwhile, Jasinga-Leuwiliang and Bogor PFMU have almost the same pattern; coffee trees are more dominant than other multipurpose plants.

Mean Annual Carbon Increment between Monoculture and Agroforestry

The land system management found are monoculture and agroforestry. Bogor FMU develop agroforestry with the local farmers called forest village community. To find out the comparison of agroforestry carbon absorption with monoculture, further described biomass, carbon absorption, carbon stock, and carbon increment between agroforestry and monoculture patterns of 7 sample agroforestry plots and 2 sample monoculture plots on 4 PFMU can be seen in Table 3.

Based on the results of the analysis, it is known that AF-1, AF-2, and AF-4 plots, which are filled with young plants, have low carbon stores. In sample plots containing high-aged plants, good and very good carbon stocks were found. The accumulation rate of carbon storage continues to increase as the plant ages [36]. In the AF-5 plot, the plants found are durian and mango, which had an average age of 23 years, but had poor carbon storage. This shows that carbon storage also needs to be reviewed based on the age of plants. The amount of carbon stored in woody plants is determined by the age of planting, stem density, soil conditions, weather conditions, and land management practices [37]. In addition, in fruit plants, absorbed carbon is stored in fruit, stems, branches, leaves, flowers, fruits, and plant roots [38], where every harvest season, the fruit is taken for trading. So, the carbon storage of fruit plants tends to be lower than that of agroforestry, which combines timber and fruit plants.

Table 3. Estimation of carbon stocks and carbon increment of agroforestry and monoculture samples.

No.	Plot	Location	Main timber-plants	Amount type of plants	Plant age average	Biomass ton H-1	Carbon stock ton H-1	MACI ton H-1
1	AF-1	Parung panjang	Teak	3	2.05	14.42	7.61 poor	66.65
2	AF-2	Parung panjang	Teak, mahogany	2	2.00	11.83	6.02 poor	18.01
3	AF-3	Jonggol	Acacia	5	13.11	390.07	183.69 excellent	20.25
4	AF-4	Jasinga-leuwiliang	Pine	2	2.00	12.44	5.85 poor	3.31
5	AF-5	Jasinga-leuwiliang	-	2	23.00	54.73	25.72 poor	2.26
6	AF-6	Bogor	Pine	5	17.67	207.61	97.58 good	27.29
7	AF-7	Bogor	Pine	11	20.15	133.12	72,27 good	64,14
8	M1	Parung panjang	Mahogany	1	20.00	580.69	272.92 excellent	13.65
9	M2	Jasinga-leuwiliang	Meranti	1	15.00	583.59	274.29 excellent	18.29

MACI: Mean Annual Carbon Increment

Based on the carbon increment analysis results, the highest carbon increment was in the AF-1 and AF-7 plots. In the AF-1 plot, a combination of young main timber plants, herbs, and sorghum was found. Then, in the AF-7 plot, it was found that many types of plants have different planting years, so the carbon increment is high. Meanwhile, low carbon increment was found in AF-4, AF-5, and monocultures. The AF-4 plot is filled with 2-year-old pine and 2-year-old coffee, while the AF-5 plot consists of old fruit trees, so the carbon increment is low. Then, the carbon increment of monoculture is low because the age of the plants reaches 20 years, so the ability to absorb carbon is slowed down. Herbs are the fastest-growing vegetation, with the highest relative mean increment value [39]. Meanwhile, shrubs and trees have the lowest, possibly due to physiological processes and the nature of vegetation. This explains the highest carbon in AF-1 and AF-7, while the others have lower carbon increments.

One part of assessing climate change mitigation through agroforestry is estimating the existing carbon storage [40]. From the results of this analysis, it can be interpreted that carbon storage can be affected by the type, age, and diversity of agroforestry plants of more than 5 types of plants. The mean annual carbon increment between agroforestry and monoculture patterns shows that agroforestry has a higher annual increment value. So, the agroforestry system is feasible for climate change mitigation because of its diversity.

Estimated Carbon Revenue of Agroforestry Scheme

The estimated revenue of agroforestry's carbon absorption are shown in Table 4. The revenue based on the FCPF program resulted in a range of IDR 1,547,325 to IDR 49,292,405 per hectare. If carbon trading uses the Social Cost rate set by the US government, the range of carbon revenue is IDR 12,997,535 to IDR 414,056,204 per hectare. Meanwhile, if trading is conducted in the domestic market using prices based on the UU HPP, the carbon absorption value obtained is between IDR 635,017 to IDR 20,229,441 per hectare in the year of study. The larger the area of land managed, the greater the carbon revenue will obtain.

Climate change mitigation efforts are long-term action, in this study the specified timeframe is 20 years. The benefit transfer method is used to measure the value of environmental services in 2043 based on the current carbon value. The inflation rate is based on the annual inflation target from Bank Indonesia in 5 years at intervals of 3 to 5%; in fact, actual inflation in 2016 to Jul 2023 (excluding 2020–2021 for anomaly data caused by Covid-19) is around 2.06 to 5,95%. So, the inflation rate used is 4%.

Table 4. Estimation of carbon revenue for each agroforestry system in the research location.

No.	Sample	Carbon absorbed (tCO_2e)	Estimation of carbon revenue (2023)			Estimation of carbon revenue (2043)		
			Carbon price (FCPF)	Social cost	Domestic carbon tax	Carbon price (FCPF)	Social cost	Domestic carbon tax
1	AF-1	27.95	2,042,961	17,160,872	838,424	4,476,379	37,601,584	1,837,091
2	AF-2	22.16	1,615,803	12,997,536	635,017	3,390,381	28,479,201	1,391,401
3	AF-3	674.31	49,281,500	414,056,205	20,229,441	108,005,730	907,248,133	44,325,197
4	AF-4	21.46	1,568,713	13,177,185	643,794	3,437,242	28,872,836	1,410,633
5	AF-5	94.41	6,901,148	57,969,643	2,832,208	15,121,265	127,018,627	6,205,718
6	AF-6	358.12	26,178,338	219,898,036	10,743,504	57,359,961	481,823,675	23,540,340
7	AF-7	229.62	19,389,441	162,871,303	7,957,363	42,484,652	356,871,081	17,435,562

The results obtained for the value of environmental services in all samples in 2043 will increase by 2.19 times from 2023. Climate change mitigation efforts with agroforestry provide great potential to be developed. The wider the area of land managed using agroforestry system and the variety of types of plants planted, the higher the estimated economic value of carbon absorption. It is not only impact on nature but also add more income for local farmers.

Conclusion

The agroforestry system at each part of Bogor Forest Management Unit (PFMU) varies according to the condition of the land and the characteristics of Perhutani Staple Plants. Parung Panjang PFMU's agroforestry system is planted with Perhutani's staple crops, namely teak, and is planted with understorey plants, namely sorghum, galangal, and papaya. Jonggol and Jasinga-Leuwiliang PFMU, the multipurpose plants planted are fruit trees. Meanwhile, Jasinga-Leuwiliang and Bogor PFMU have almost the same pattern; coffee is more dominant than other multipurpose crops due to favorable geographical and weather conditions. High carbon stock found in agroforestry that consists of more than 5 plants. The highest carbon stock among 7 samples is AF-3, with a stock of 183.74 tons of C, which consists of 5 types of plants. Monocultures store a high amount of carbon, but the mean annual carbon increment is low because the age of the plantation is more than 15 years. The estimation of carbon economic valuation using FCPF Program results is a minimum of IDR 1,547,326 and a maximum of IDR 49,292,405 per hectare in the year. Meanwhile, based on the Social Cost result, the minimum is IDR 12,997,536, and the maximum is IDR 414,056,205 per hectare. According to UU HPP, the minimum IDR is 635,017, and the maximum is 20,229,441 per hectare. Using the benefit transfer method, the results obtained for the value of environmental services in 2043 will increase by 2.19 times. Therefore, it is suggested that carbon-based agroforestry in Bogor Forest Management Unit is potentially developed, whit strategic type of carbon absorption plants while providing direct economic benefit to farmer. Also, counseling and assistance are needed regarding climate mitigation based on carbon sequestration for farmers at Parung Panjang and Jasinga-Leuwiliang PFMU because farmers in these two area show carbon absorption values that tend to be lower than other farmers.

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