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REGULAR RESEARCH ARTICLE

The role of social forestry in achieving NDC targets: Study cases of Lampung and DI Yogyakarta

Alfi Syakila [1,*], Noverita Dian Takarina [2], Raldi Hendro Koestoer [1], and Moira Moeliono [3]

AFFILIATIONS

1. School of Environmental Science, Universitas Indonesia, Jakarta, Indonesia
2. Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Jakarta, Indonesia
3. CIFOR-ICRAF, Bogor, Indonesia

*Corresponding author: alfisyakila@gmail.com

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ABSTRACT

Social Forestry (SF) in Indonesia has emerged as a keystone strategy for Sustainable Forest Management. By allocating 12.7 million ha of forest to be managed by local communities, the government has set in motion an ambitious plan for SF to reduce poverty, empower local people, and improve forest conditions. More recently, SF is framed for its opportunity to contribute to climate change mitigation and adaptation. This study focused on examining the contribution of SF to the Nationally Determined Contribution (NDC) goals in Yogyakarta and Lampung. By analyzing spatial data of SF areas and land cover changes using ArcView 10.8, the study assessed the carbon stock potential in SF areas. Carbon stock calculations were based on the 2022 National Forest Reference Level (FRL) for the periods before and after SF implementation. The finding of the study indicated that the carbon stock of SF areas in Yogyakarta and Lampung ranged from 9,214,381 to 9,923,420 ton CO2eq prior to SF, while the current carbon stock ranges from 8,703,489 to 9,393,706 ton CO2eq, representing a decrease (around 5.4%) rather than an increase. Overall, the changes in carbon stock were relatively small and localized, and the magnitude of the increase was insufficient to offset the overall decrease. To achieve the objectives of SF, such as meeting emission targets and achieving sustainable land use, it is crucial to carefully manage forest edges and fragmented forests, as they can contribute to carbon stock losses. Additionally, further studies and research are needed to improve the accuracy of carbon stock calculations, particularly for non-forest categories, which have higher uncertainty in the reference levels.

KEYWORDS

Social forestry; NDC; Carbon stock; Forest Reference Level (FRL); Sustainable Forest Management (SFM).

1. INTRODUCTION

Tropical forests cover 15% of the earth's surface and have been shown to act as carbon sinks as CO_2 is actively removed from the atmosphere and assimilated into biomass (Lewis et al., 2004; Phillips et al., 1998). This carbon-absorbing function is not limited to pristine primary forests, as secondary forests have been shown recently to be key players in the mitigation against global climate change (Bongers et al., 2015). Conversely, clearing forests releases this stored carbon. Therefore, forests play a crucial role in mitigating climate change, particularly in Indonesia where designated forests cover more than 60% of the land area (Grassi *et al.*, 2017; Rockström *et al.*, 2017; Tacconi & Muttaqin, 2019). The Updated Nationally Determined Contribution (NDC) and Forest and Other Land Use (FOLU) Net Sink 2030 documents mention the importance of forests in mitigation of climate change, particularly maintaining green house gases (GHG) sequestration and avoiding the increases of emissions.

Forest fires and land clearing is recognized as a major source of emission (Cahyono et al., 2022; Directorate General of Climate Change, 2021). To reduce emissions from the land use sector, Indonesia has instituted a moratorium on the clearing of primary forests and initiated programs for reducing deforestation and forest degradation (REDD), restoring ecosystem functions, as well as sustainable management of forest. Social Forestry (SF) is considered an important strategy for implementing these steps. The SF program aims to involve active participation of multiple stakeholders, such as sub national governments, private sector, small and medium enterprises, civil society organizations, local communities and customary communities (Indonesia: Masyarakat Hukum Adat), and women, in both the planning and implementation stages of forest management (Directorate General of Climate Change, 2021; KLHK, 2021). The SF program provides five SF schemes, namely: Community Forest (CF, *Hutan Kemasyarakatan* or HKm), Village Forest (VF, *Hutan Desa* or HD), Community Plantation Forest (CPF, *Hutan Tanaman Rakyat* or HTR), Partnership (*Kemitraan*) and Customary Forest (*Hutan Adat* or HA). CF is one of the earliest forms of SF, and is implemented by organized groups of communities, farmers, or cooperatives. Meanwhile VF is managed by a village organization or groups of village organizations. CF and VF can be applied in production and protection forests. CPF can only be implemented in production forests, by individual farmers, farmer associations or local cooperatives. The Partnership scheme can be implemented in production, protection, and conservation forests, through establishing partnerships with other actors. The last scheme, customary forest, involves recognition of customary communities and their territories (Firdaus, 2018; Fisher et al., 2018; Kementerian Lingkungan Hidup dan Kehutanan, 2021; Maryudi et al., 2012; Moeliono et al., 2017; Rakatama & Pandit, 2020).

Although the understanding of SF's impact on carbon stock is still limited, several studies have provided insights into the relationship between SF activities, carbon stock as well as forest cover (Putraditama et al., 2021; Resosudarmo et al., 2019; Sadono et al., 2020; Santika et al., 2017). A study conducted by Sadono et al. (2020) in Gunung Kidul demonstrated a significant increase in carbon stock in a CF area. Prior to the implementation of CF, the carbon stock was recorded as 312.09 ton C during the period from 1999 to 2003. This increased to 1,352.62 ton C during the preparation stage from 2003 to 2009, and further increased to 1,840.94 ton C post CF permit (2009 to 2018). Santika et al. (2017) found that VF in Lampung successfully avoided deforestation overall. However the program's performance has shown increasing variability over time. Putraditama et al. (2019) found that SF is less effective than Conservation Forests (e.g. National Parks) in reducing forest cover loss but more effective than other similar forests without SF management. This provides a promising starting point for expanding SF in Indonesia to achieve NDC targets.

Recognizing the importance of SF in reducing emissions, Indonesia set a target in 2011 to allocate 2.5 million ha of state forests to SF (Presidential Decree/ *Perpres* No 61/20211), with a potential to contribute to a reduction of 91,75 million ton CO_2eq. Given the ambitious target of expanding SF to 12.7 million ha, SF's contribution to emissions reductions could potentially reach 400 million ton CO_2eq, which is nearly 30% of the country's total greenhouse gases (GHG) in 2010 (Directorate General of Climate Change, 2021).

The objective of this study is to review and analyze the carbon stock potential in SF areas, with particular focus on DI (*Daerah Istimewa*)[1] Yogyakarta and Lampung province, Indonesia. These two provinces were among the first to implement SF when it was introduced in Indonesia. We ask, to what extent does SF contribute to improving carbon stocks and achieving NDC targets. With the recent publication of the National Forest Reference Level (FRL)/Forest Reference Emission Level (FREL) for Deforestation,

[1] Literally meaning "special region," and refers to the name of the administrative region.

Forest Degradation and Enhancement of Carbon stock, it is an opportune time to estimate the carbon stock in SF areas.

2. METHODS

Prior to 2016, the issuance of SF permits involved multiple entities, including the Ministry of Forestry, governors, and mayors. However, since 2016, the responsibility for issuing SF permits has shifted to the Ministry of Environment and Forestry (MOEF), with the option to delegate issuance of permits to governors under specific conditions. In the past, spatial information, referred to as the Work Area Map (*Peta Areal Kerja* or PAK), was integrated into the Indicative Map and Social Forestry Area (*Peta Indikatif dan Area Perhutanan Sosial* or PIAPS) that is updated every six months (Firdaus, 2018; Fisher et al., 2018). PIAPS provides spatial information of various SF schemes, including the number of SF areas, SF boundaries, and land cover. This study is highly dependent on the data provided by the MOEF to gain a comprehensive understanding of SF areas and its land cover changes. The presence of reliable spatial data is essential for conducting accurate analyses and comprehending the characteristics of SF areas. Unfortunately, changes in regulation and data management resulted in a limited availability of spatial data within the MOEF and consequently, SF areas lacking spatial data were excluded from the study.

2.1 Study area

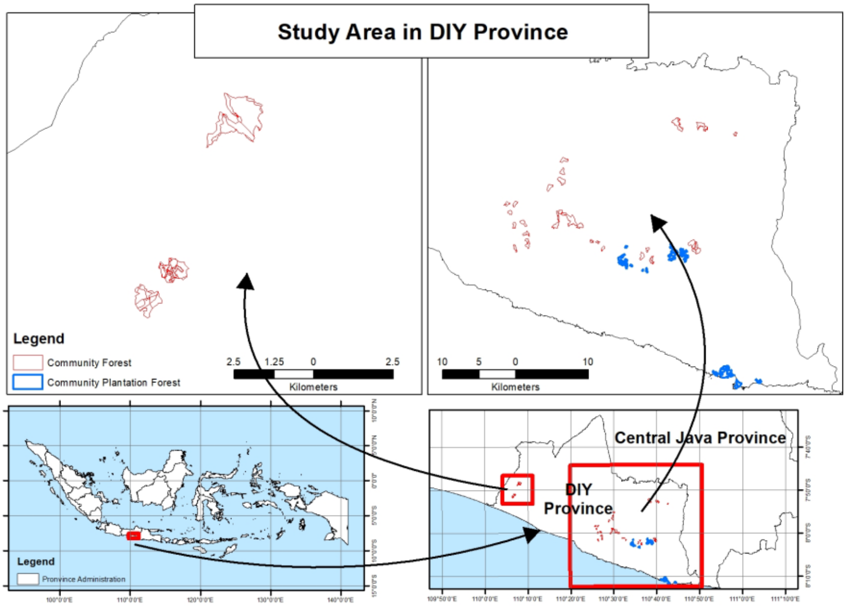

Figure 1. SF areas in DI Yogyakarta

In DI Yogyakarta, CFs were established in Gunung Kidul and Kulon Progo in 2007, while CPFs were established in Gunung Kidul in 2009. Some literatures indicate that temporary permits for CF were already issued since 2002, and the initial stage started in the period from 1999 to 2003 (Sadono et al, 2020; Supriyanto et al, 2018). Therefore, for CF in DI Yogyakarta, the baseline conditions prior to the establishment of the SF are considered to be from 2000, as it is the closest available data. The initial CF implementation is marked as 2009, and the current state represented by the year 2020.

To assess significant changes in land cover within two-year intervals (2000 to 2002), the same time frame of 2009 to 2011 was analyzed. As for CPF, the regulation was launched in 2002, and permits were issued in 2009. Thus, the baseline for CPF is 2009 to represent the condition prior to SF, 2011 to represent early stage of CPF, and 2020 to represent the current condition. Figure 1 shows the study area in DI Yogyakarta, located in Gunung Kidul and Kulon Progo.

The study area in Lampung adopts a different approach due to variations in the issuance of CF permits over time. According to MOEF, CF initiatives began in 2007 in three districts: West Lampung, North Lampung, and Tanggamus. In 2007, the total CF area was 5,717.31 ha. Kaskoyo et al. (2017) reported that in 1999, the CF area in Lampung Province was 495.2 ha, which increased to 35,718.61 ha by 2011. Putraditama et al. (2019) recorded that in 2016, the CF area in Lampung reached approximately 110,257 ha, making it the largest in Indonesia. However, spatial data provided by the MOEF regarding CF in Lampung is only available for permits issued during the period from 2017 to 2020, totalling 62,506 ha. To examine the relationship between carbon stock and SF activities, the study area focuses on CF established in 2017. Therefore, the baseline represents the year 2016, which reflects the conditions prior to SF implementation, while the year 2020 represents the current situation with a CF area of 20,922.30 ha. The same approach is applied to VF and CPF, as all permits were issued in 2017, making 2016 the baseline year (Figure 2).

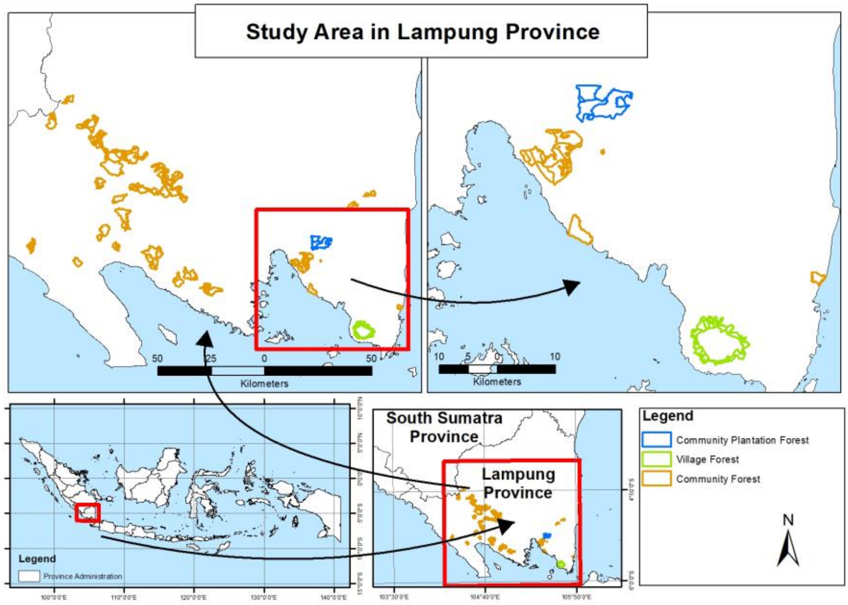

Figure 2. SF areas in Lampung

2.2 Forest Reference Level (FRL)

This study applies the Forest Reference Level (FRL) as a reference to estimate the carbon stock in SF areas. The FRL was recently updated in 2022, incorporating several improvements. These improvements include the inclusion of carbon pools such as Above Ground Biomass (AGB), Below Ground Biomass (BGB), dead wood, litter, and soil; an updated approach to allometric equations; and enhancement of forest carbon stock (Indonesia, 2022).

The FRL covers 23 land cover classes divided into two categories, namely forest area and non-forest area. The definition of a forest is a land area exceeding 6.25 ha with trees reaching a height of over 5 meters at maturity and a canopy cover of more than 30 percent. The forest areas comprise 6 land cover classes, namely Primary dryland forest; Secondary dryland forest; Primary mangrove forest; Secondary mangrove forest; and Primary swamp forest. For the non-forest category, the land cover classes is: Plantation Forest; Estate crop; Pure dry agriculture; Mixed dry agriculture; Dry shrub; Wet shrub; Savanna and grasses; Paddy field; Open swamp; Fish pond/aquaculture; Transmigration areas; Settlement areas; Port and harbor; Mining areas; Bare ground and Open water (Indonesia, 2022).

The emission factor for the forest category is based on the data generated from the Permanent Sample Plot (PSP), while for mangroves, Temporary Sample Plot (TSP) data is applied. On the other hand, for the carbon stock in the non-forest category, data generation relies on various references. It should be noted that the uncertainty analysis is only available for the non-forest category and not for the forest category. The uncertainty in the non-forest category is relatively high, exceeding 50%, particularly in areas such as Pure dry (91.10%); Settlement areas (85.18%); Bare ground (92.17%); Savanna and grasses (77.88%); Paddy field (63.27%) and Transmigration areas (91.1%) (Indonesia, 2022). While this study acknowledges these limitations, the main objective is to explore the carbon stock potential in SF areas and assess whether the SF activities contribute to the improvement or reduction of carbon stocks. Therefore, the available reference can still be applied, as they provide valuable information on AGB and BGB for both the forest and non-forest categories, as well as complete carbon pools for the forest category, including standard error (SE).

2.3 Calculation of the Carbon Stock

The study employed land cover data and SF area boundaries provided by the MOEF. To estimate carbon stock, the study utilized the reference value from the FRL document, which provides information on carbon stock in various land cover categories. The steps applied in this study involved multiplying the activity data and carbon stock factor based on FRL (Indonesia, 2022; Sadono et al., 2020; Tosiani, 2015). Firstly, the activity data was collected by overlaying the land cover map data for the designated year with the SF boundaries using ArcView 10.8. This process enabled the extraction of land cover within SF areas for different SF schemes and different years. Second, the land cover within the SF areas obtained from the previous step was multiplied by the carbon stock reference values from the FRL (Tosiani, 2015). The result of this calculation provides the carbon stock in ton per hectare (ton/ha) for each SF area, along with the SE to account for the range of values. To calculate the CO_2 equivalent (CO_2 eq), the amount of carbon stock is multiplied by 44/12 (Tosiani, 2015). This conversion factor is based on the atomic weight of carbon (C = 12 daltons) and the molecular weight of CO_2 (44 daltons). By following these steps, the study derived estimates of carbon stock and CO_2 equivalent for the calculated SF areas based on the land cover data, SF boundaries, and carbon stock reference values from the FRL.

3. RESULTS

In DI Yogyakarta, the SF schemes consist of CF and CPF, covering 1,351.03 ha and 394.5ha, respectively. Slight land cover changes were observed in both CF and CPF areas during the periods prior and after SF activities, as presented in Table 1. Table 1 shows the percentages of each land cover category relative to the total area of each scheme. It is worth noting that in DI Yogyakarta, both CF and CPF schemes are located under the non-forest category.

In the CF scheme, located in Gunung Kidul and Kulon Progo, land cover changes were observed during the period 2000 to 2020. These changes occured in a number of areas of plantation forest, mixed dry agriculture, settlement areas and bareground. From 2000 to 2009, there was a decrease in plantation forest, with a corresponding increase in mixed dry agriculture. The percentage of plantation forest decreased from 83.08% to 61.91%, while mixed dry agriculture increased from 11.97% to 33.14%. The data also shows that mixed dry agriculture in 2009 converted into settlement areas by 2011, resulting in an increase of settlement areas (from 0.02% to 0.11%). The majority of the mixed dry agriculture originally located in Kulon Progo experienced a reduction in 2020, leading to the conversion of land into settlement areas, bareground, and plantation forest. There were no significant changes observed from 2009 to 2011. Therefore, this study proposes that a similar pattern of insignificant change occurred from 2000 to 2002. For that reason, the year 2000 can be considered as the baseline to represent land cover conditions prior to the implementation of SF.

Table 1. Land cover changes in Community Forest and Community Plantation Forest area, DI Yogyakarta

	Land cover (ha) (%)						
SF scheme	**Community Forest**				**Community Plantation Forest**		
Land cover class	**2000**	**2009**	**2011**	**2020**	**2009**	**2011**	**2020**
Non forest category							
Plantation forest	1,122.41 (83.08%)	836.40 (61.91%)	836.40 (61.91%)	1,074.06 (79.50%)	6.46 (1.64%)	6.46 (1.64%)	9.72 (2.42%)
Pure dry agriculture	66.58 (4.93%)	66.58 (4.93%)	66.58 (4.93%)	0	2.30 (0.58%)	30.32 (7.68%)	114.28 (28.97%)
Mixed dry agriculture	161.74 (11.97%)	447.75 (33.14%)	446.51 (33.05%)	245.28 (18.16%)	378.76 (96.01%)	350.74 (88.90%)	263.52 (66.80%)
Paddy field					2.88 (0.73%)	2.88 (0.73%)	2.88 (0.73%)
Settlement areas	0.29 (0.02%)	0.29 (0.02%)	1.53 (0.11%)	14.98 (1.11%)	4.11 (1.04%)	4.11 (1.04%)	4.11 (1.04%)
Bare ground				16.71 (1.24%)			
Total	1,351.03	1,351.03	1,351.03	1,351.03	394.51	394.51	394.51
Total SF area in DI Yogyakarta: 1,745.54							

In the CPF, there have been significant changes in land cover, particularly in the area of plantation forest, pure dry agriculture, and mixed dry agriculture. The proportion of plantation forest in CPF is relatively small, accounting for 1.64% in 2009, and slightly increasing to 2.41% in 2020. The pure dry agriculture area experienced a substantial increase, rising from 0.58% in 2009 to 28.97% in 2020. On the other hand, the mixed dry agriculture area decreased from 96.01 % in 2009 to 66.80% in 2020. This shift is primarily due to the conversion of mixed dry agriculture into pure dry agriculture and plantation forest areas.

In this study, the SF areas in Lampung cover a total area of 26,447.14 ha and consist of CF, VF and CPF schemes. The largest proportion of SF areas is attributed to the CF. These SF schemes are distributed in both forest and non-forest categories. A small portion of CF and VF scheme is located within the secondary dryland forest, meanwhile all CPF area found in the non-forest category as shown in Table 2.

The CF areas examined in this study are spread across the locations of West Lampung, South Lampung, East Lampung, North Lampung, Pringsewu and Tanggamus, with a total area of 20,922 ha. Overall, there have been no significant changes in CF areas, except for changes in secondary dryland forest, dry shrub, and settlement areas. The secondary dryland forest areas have decreased from 5.14% in 2016 to 3.25% in 2020. On the other hand, the dry shrub area has increased from 4.70% in 2016 to 5.66% in 2020. A small settlement area has emerged in 2020, accounting for 0.08%.

In VF, the total area is 2,014.37ha, and all VF areas are located in South Lampung, specifically in the protection forest. There have been no significant changes in land cover in VF area, except for a slight increase of secondary dryland forest from 28.90% in 2016 to 29.05% in 2020. In the CPF scheme, also located in South Lampung, the total area is 3,510.47ha. The percentage of mixed dry agriculture has decreased from 86.62% in 2016 to 78.36% in 2020, and settlement area has increased from 6.93% in 2016 to 15.19% in 2020.

In DI Yogyakarta, the CF scheme is primarily managed on a smaller scale, with an average area of 40ha. On the other hand, in Lampung, the CF area varies from 200ha to 4,000ha. CFs in DI Yogyakarta are located in protection forests and potentially other categories, while clear data on CF in Lampung is not available. For the VF scheme, the land area ranges from 11ha to 180ha, located in protection forests in Lampung. In the case of CPF, the land area ranges from 200ha to 1,600 hectares. The data specifies that all CPF areas in DI Yogyakarta and Lampung are located in production forests.

Table 2. Land cover changes in Community Forest, Village Forest and Community Plantation Forest areas, Lampung

	Land cover (ha) (%)					
	Community Forest		**Village Forest**		**Community Plantation Forest**	
Land cover class	**2016**	**2020**	**2016**	**2020**	**2016**	**2020**
Forest category						
Secondary dryland forest	1,076.31 (5.14%)	680.89 (3.25%)	582.20 (28.90%)	585.25 (29.05%)		
Non- forest category						
Plantation forest						
Estate crop					226.43 (6.45%)	226.43 (6.45%)
Pure dry agriculture	591.24 (2.83%)	591.24 (2.83%)	89.91 (4.46%)	90.95 (4.52%)		
Mixed dry agriculture	18,203.76 (87.01%)	18,379.13 (87.84%)	1,242.12 (61.66%)	1,238.03 (61.46%)	3,040.82 (86.62%)	2,750.78 (78.36%)
Dry shrub	984.31 (4.70%)	1,183.20 (5.66%)	91.60 (4.55%)	91.60 (4.55%)		
Paddy field	39.13 (0.19%)	39.13 (0.19%)				
Settlement areas		17.71 (0.08%)	3.15 (0.16%)	3.15 (0.16%)	243.22 (6.93%)	533.26 (15.19%)
Bare ground	0.85 (0%)	4.30 (0.02%)	5.39 (0.27%)	5.39 (0.27%)		
Open water	26.70 (0.13%)	26.70 (0.13%)				
Total	20,922.30	20,922.30	2,014.37	2,014.37	3,510.47	3,510.47
Total SF areas in Lampung: 26,447.14						

Based on the land cover changes presented in Table 1 and Table 2, carbon stock in SF areas in DI Yogyakarta and Lampung was calculated using the carbon stock reference values obtained from FRL (Indonesia, 2022). The result is presented in Table 3 and 4 respectively.

Table 3. Carbon stock in Community Forest and Community Plantation Forest area, DI Yogyakarta

	Community Forest				Community Plantation Forest		
Year	**2000**	**2009**	**2011**	**2020**	**2009**	**2011**	**2020**
Land cover	ton CO_2eq	ton CO_2eq	ton CO_2eq	ton CO_2eq	ton CO_2eq	ton CO_2eq	ton CO_2eq
Non- forest category							
Plantation forest	380,644-445,752	283,649-332,166	283,649-332,166	364,246-426,549	2,192-2,567	2,192-2,567	3,296-3,859
Pure dry agriculture	2,207-6,040	2,207-6,040	2,207-6,040		76-208	1,005-2,750	3,788-10,367
Mixed dry agriculture	44,603-47,391	123,476-131,193	123,134-130,829	67,642-71,869	104,450-110,977	96,723-102,767	72,671-77,212
Paddy field					88-173	88-173	88-173
Settlement areas	2-4	2-4	9-23	87-220			
Bare ground				97-246			
Total	427,456-499,187	409,335-469,403	409,000-469,058	432,073-498,884	106,807-113,926	100,008-108,257	79,843-91,611

Note: the interval value indicated the lowest to highest of carbon stock in CO_2eq

Table 3, shows that in the CF areas, carbon stock has increased from the period prior to CF implementation to the current condition, with a range of 427,456-499,187 ton CO_2eq in 2000 to 432,073-498,884 ton CO_2eq in 2020. On the other hand, the CPF areas show a decrease in carbon stock, with a range of 106,807-113,926-ton CO_2eq in 2009, and it decreased to 79,843-91,611 ton CO_2eq in 2020.

As Table 4 shows, carbon stock in the CF Forest areas has decreased from the period prior to SF and to the current condition. The carbon stock ranged from 6,673,291-7,075,752 ton CO_2eq in 2016 to 6,260,194-6,729,020 ton CO_2eq in 2020. For VF, there are slight changes, with a tendency to increase from 1,119,940-1,196,333 ton CO_2eq in 2016 becomes 1,122,785-1,199,402 ton CO_2eq in 2020. In CPF area, there is a decrease from 886,887-955,504 ton CO_2eq in 2016 to 808,594-874,789 ton CO_2eq in 2020.

Table 4. Carbon stock in Community Forest, Village Forest and Community Plantation Forest areas, Lampung

	Community Forest		Village Forest		Community Plantation Forest	
Year	**2016**	**2019**	**2016**	**2019**	**2016**	**2019**
Land cover	ton CO_2eq	ton CO_2eq	ton CO_2eq	ton CO_2eq	ton CO_2eq	ton CO_2eq
Forest category						
Secondary dryland forest	1,389,831-1,472,549	879,229-931,557	751,794-796,539	755,733-800,712		
Non- forest category						
Estate crop					46,901-58,940	46,901-58,940
Pure dry agriculture	19,598-53,634	19,598-53,634	2,980-8,156	3,015-8,250		
Mixed dry agriculture	5,020,050-5,333,762	5,068,411-5,385,145	342,539-363,945	341,411-362,746	838,568-890,971	758,584-805,989
Dry shrub	242,606-296,166	291,627-356,009	22,577-27,561	22,577-27,561		
Paddy field	1,201-2,346	1,201-2,346				

	Community Forest		Village Forest		Community Plantation Forest	
Year	2016	2019	2016	2019	2016	2019
Land cover	ton CO_2eq	ton CO_2eq	ton CO_2eq	ton CO_2eq	ton CO_2eq	ton CO_2eq
Settlement areas		103-260	18-46	18-46	1,418-3,576	3,109-7,841
Bare ground	5-14	25-69	31-86	31-86		
Open water	0	0				
Total	6,673,291-7,158,470	6,260,194-6,729,020	1,119,940-1,196,333	1,122,785-1,199,402	886,887-955,504	808,594-874,789

Note: the interval value indicated the lowest to highest of carbon stock in CO_2eq

To enhance understanding of carbon stock dynamics in the SF areas, Figure 3 and Figure 4 present a visual representation of the changes of carbon stock and land cover changes of CPF in DI Yogyakarta and Lampung, respectively.

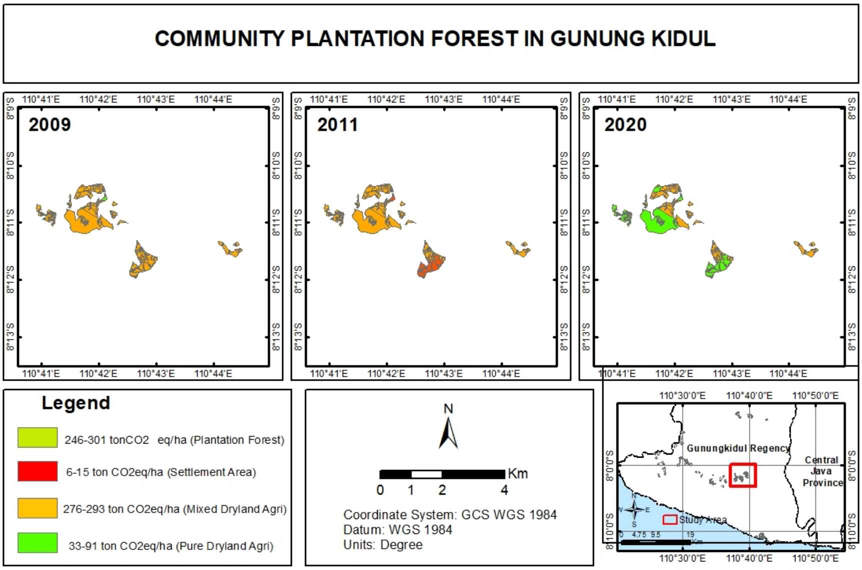

Figure 3. Land cover and carbon stock in CPF, Gunung Kidul, DI Yogyakarta.

Figure 3 illustrates land cover changes in Gunung Kidul over time. In 2009, mixed dry agriculture was the dominant land cover category as indicated in Table 1. There was a slight change in 2011. However, by 2020, there was a noticeable increase in pure dry agriculture, indicating a shift in land cover composition.

Figure 4 illustrates land cover changes in CPF area in South Lampung. The figure shows that an increase in settlement areas over time. Additionally, there is a decrease in mixed dry agriculture, as indicated in Table 2.

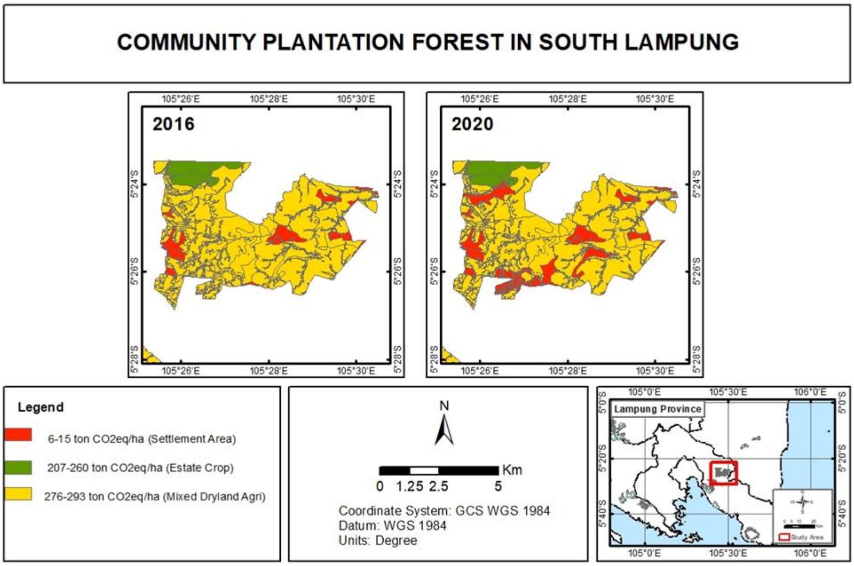

Figure 4. Land cover and carbon stock in CPF, South Lampung

4. DISCUSSIONS

The study indicates that DI Yogyakarta has experienced a slight change in land cover and carbon stock over a long time period, ranging from 2000 to 2020 for CF and from 2009 to 2020 for CPF (see Table 2 and Table 3). On the other hand, the analysis for Lampung Province, although covering a shorter time period from 2016 to 2020 for all SF schemes, yielded similar findings. These findings highlight the dynamic nature of land cover and its potential impact on carbon stock in SF areas, regardless of the specific time period analyzed.

The CF scheme in DI Yogyakarta and Lampung initially showed a decrease in carbon stock during the early stage (2009-2011 in DI Yogyakarta and 2020 in Lampung) compared to the baseline (2000 in DI Yogyakarta and 2016 in Lampung). However, in DI Yogyakarta, the carbon stock tended to increase over the longer period of SF due to the expanding area of plantation forest. This result aligns with previous studies conducted by Dewi et al. (2018) and Supriyanto et al. (2018) that also reported an increase in plantation forest area. The region has been actively involved in the policy on forest and land rehabilitation movement (*Gerakan Rehabilitasi Hutan dan Lahan/ Gerhan*) (Oktalina et al., 2015), which may have contributed to increases in land cover, particularly in protection forest areas of Gunung Kidul and Kulon Progo.

Local communities have utilized these areas for ecotourism activities, which has played a significant role in supporting their livelihoods. Further analysis is needed to determine whether the CF in Lampung will follow a similar trajectory as the CF in DI Yogyakarta, where there has been an increase in land cover and carbon stock over the longer period of CF establishment. Concerns arise in the CF in Lampung due to the increase in bare ground and settlement areas resulting from the conversion of secondary dryland forest. A study by Putraditama et al. (2019) indicates that CF areas exhibit a higher percentage of tree cover loss compared to conservation forests but a lower percentage of tree cover loss compared to protection forests. Several studies conducted in Lampung have highlighted the positive outcomes of CF activities in terms of improving livelihoods and addressing tenurial conflicts (Kaskoyo et al., 2017;

Puspasari et al., 2017; Sanudin et al., 2016). However, if the goal is to increase carbon stock in SF areas, this study suggests that it may be challenging to achieve based on the performance of land cover in Lampung.

In the case of CPF implemented in production forests, both provinces have experienced a decrease in carbon stock. In DI Yogyakarta, the land cover has shifted from mixed dry agriculture to pure dry agriculture, while in Lampung, there has been an increase in settlement areas resulting from the conversion of mixed dry agriculture. Studies have indicated that smallholders involved in CPF face numerous problems, such as uncertain financial feasibility, limited tenure incentives, and limited knowledge of silviculture practices in managing timber trees (Obidzinski & Dermawan, 2010; Race et al., 2019; Rohadi et al., 2010; Stewart et al., 2021). These findings suggest that the current approach in CPF may not effectively contribute to increasing carbon stock in SF areas.

The analysis of VF in Lampung demonstrates a small increase in the area covered by secondary dryland, which is accompanied by an increase in carbon stock. This finding aligns with a study by Santika et al., (2017), which highlights the positive performance of VF in protection forests. VF allocated in watershed protection forests or limited production forests typically exhibit lower rates of deforestation regardless of their location. Conversely, VF granted in permanent or convertible production forests exhibit variable performance across different years and locations. In this study, since all VF areas are located in protection forests, there is an observed small increase of carbon stock.

The findings of the study indicate that there is slight variation in the performance of land cover across all SF schemes in both DI Yogyakarta and Lampung. The changes in carbon stock are observed to be relatively small and localized, and in cases where there is an increase, the magnitude is insufficient to offset the overall decrease (Table 3 and Table 4). In total, the carbon stock in both provinces prior to the implementation of SF ranged from 9,214,381 to 9,923,420 ton CO_2eq while the current carbon stock ranges from 8,703,489 to 9,393,706 ton CO_2eq, representing a decrease (around 5.4%) rather than an increase. As explained earlier, SF is closely linked to livelihood activities, and balancing the objectives of maintaining land cover and generating economic benefits can be challenging. Additionally, it is important to note that the areas allocated for SF are predominantly in non-forest categories, which typically have lower carbon stock compared to forested areas. These factors contribute to the complexity of achieving both land cover conservation and increased carbon stock within the SF scheme. However, this study suggests that the observed decrease in carbon stock in SF areas is not directly attributed to the SF scheme itself. Instead, it is due to the effect of the outside forestry domain such as economic factors, institutions, national policies, and remote influences (at the underlying level) driving agricultural expansion, wood extraction, and infrastructure extension (Geist & Lambin, 2002; Verbist et al., 2005).

The presence of bare ground and increasing settlement areas in CF and CPF in both Yogyakarta and Lampung is indeed concerning, especially if the objective is to meet emissions targets and achieve sustainable land use as outlined in the NDC. The dispersed nature of SF areas, combined with other influential factors, further complicates the management of forest carbon. It is well-established that conserving standing forests is crucial for maintaining high carbon storage and uptake. The carbon storage capacity of forests can vary significantly depending on factors such as climate, soil conditions, hydrology, and species composition, as highlighted in studies by Cid-Liccardi et al. (2012). The proximity of forest edges to trees and the presence of fragmented forests can potentially lead to a reduction in carbon stock. Previous studies by Chaplin-Kramer et al. (2015) and Magnago et al. (2015) have demonstrated that forest edges and fragmented forests can contribute to a decrease in carbon stock. It has been estimated that carbon stock can decline by 25% within the first 500m from the forest edge and extend up to a 10% reduction within a 1.5km range. These findings underscore the importance of carefully managing forest edges and fragmented forests to minimize carbon stock losses.

Based on the calculations of this study, the current carbon stock in SF areas ranges from 8,703,489 to 9,393,706 ton CO_2eq or from 308,714.5 to 333,196.6 ton CO_2eq/ha. Assuming these number as the carbon stock reference, and considering the SF target in FOLU Net Sink 2030 of 8million ha, the potential carbon stock from SF areas would range from 2,469,715,969 to 2,665,573,049 ton CO_2eq. This value is almost double the emission level in 2010 from the NDC, indicating that achieving the goal of utilizing SF as a net sink is possible. However, it is important to acknowledge the high uncertainty in the FRL for non-forest categories such as pure dry agriculture, settlement, and bareground, which often exist in SF areas. These land cover types have a high level of uncertainty (>85%) in the reference, which can affect the accuracy of carbon stock calculations. Therefore, if SF is expected to play a prominent role in contributing to the emissions targets, it becomes even more essential to conduct further studies and research to improve the accuracy of carbon stock calculations. This will contribute to a more robust understanding of carbon dynamics and better inform decision-making processes related to land use and climate change mitigation strategies.

The study conducted in these two provinces may not provide a comprehensive representation of the overall condition of SF areas in Indonesia. However, it offers valuable insights into the development of SF and its relevance to achieving the NDC targets from SF areas. The findings suggest that SF primarily improves land cover in protected areas, thus highlighting the multifaceted nature of SF, which encompasses both conservation and poverty reduction objectives. To balance livelihoods effectively and conservation objectives, it is crucial to further examine the trade-offs associated with SF areas through additional research.

5. CONCLUSION

This study highlights the dynamic nature of land cover and carbon stock in the SF areas of DI Yogyakarta and Lampung provinces. DI Yogyakarta exhibited an increase in carbon stock over time in the CF scheme due to the expansion of plantation forests. However, Lampung faced challenges in increasing carbon stock, with notable increases in bare ground and settlement areas within the CF scheme. In the case of CPF implemented in production forests, both provinces experienced a decrease in carbon stock due to changes in land cover. In DI Yogyakarta, the land cover has shifted from mixed dry agriculture to pure dry agriculture, while in Lampung, there has been an increase in settlement areas resulting from the conversion of mixed dry agriculture. The VF scheme in Lampung demonstrated a small increase in carbon stock, primarily in secondary dryland areas in protection forests. Overall, the changes in carbon stock were relatively small and localized, and the magnitude of increase was insufficient to offset the overall decrease.

To achieve the objectives of SF, such as meeting emission targets and achieving sustainable land use, it is crucial to carefully manage forest edges and fragmented forests, as they can contribute to carbon stock losses. Additionally, further studies and research are needed to improve the accuracy of carbon stock calculations, especially for non-forest categories, which have higher uncertainty in the reference levels.

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