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Carbon trading incentives based on emission reference in Salat Island, Pulang Pisau District, Indonesia

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[2]Laboratory of Forest Policy, Department of Forest Management, Faculty of Forestry and Environment, Institut Pertanian Bogor. Kampus IPB Dramaga, Bogor 16680, West Java, Indonesia. Tel.: +62-251-8621244, Fax.: +62-251-8626265, ♥email: dnurrochmat@apps.ipb.ac.id
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Abstract. *Ridwan M, Nurrochmat DR, Purwawangsa H, Ekayani M. 2026. Carbon trading incentives based on emission reference in Salat Island, Pulang Pisau District, Indonesia. Asian J For 10 (1): r100111. https://doi.org/10.13057/asianjfor/r100111.* Indonesia is scheduled to commence international carbon trading in 2025. The effectiveness of this mechanism depends strongly on the design of emission reference levels that determine the allocation of incentives for mitigation actions. Under Indonesian Minister of Environment and Forestry Regulation No. 21 of 2022, multiple actors, including national and subnational governments, private entities, and communities. This study is analytically novel in that it explicitly compares emission reference levels across three scales, site-level (Salat Island), sub-national (Pulang Pisau District), and island-level (major Indonesian islands), to evaluate how scale-dependent reference designs influence the equity and effectiveness of carbon trading incentives. Using the Forest Reference Level (FRL) 2022, the study evaluates how regional characteristics of deforestation influence reference emissions and, consequently, access to carbon trading incentives. The analysis adopts a comparative approach across regions representing four deforestation typologies defined in the FRL: large forest areas with high deforestation risk, large forest areas with low deforestation risk, limited forest areas with low deforestation, and limited forest areas with high deforestation risk. Quantitative comparison reveals notable disparities in annual reference emissions, including 0.46% for Salat Island, 1.06% for Pulang Pisau District, 1.27% for Java Island, -0.05% for Papua Island, and a national average of 0.39%. The results demonstrate that regions with low or negative historical deforestation, particularly Papua Island, face limited access to carbon trading incentives when uniform reference periods are applied. To address this imbalance, the study proposes four alternative emission reference scenarios for low-emission regions, incorporating national benchmarks, sub-national averages, and proportional reference adjustments. These scenarios offer policy-relevant options to enhance equity, incentive compatibility, and environmental integrity within Indonesia's forestry carbon trading framework. The findings underscore the need for a more flexible, regionally sensitive approach to emission reference design to ensure equitable participation across diverse forest landscapes. This study is novel in using specific emission references in regions with historically low emissions to obtain carbon trading incentives.

Keywords: Carbon policy, carbon trading, emission reference, forest reference level, REDD+

INTRODUCTION

Indonesia has taken significant steps toward implementing carbon economic value instruments as part of its climate change mitigation strategy. The issuance of Presidential Regulation No. 98/2021, followed by its amendment under Presidential Regulation No. 110/2025. These regulations are operationalized through derivative policies, notably the Indonesian Minister of Environment and Forestry Regulation No. 21/2022, which outlines procedures for implementing carbon economic value in the forestry sector. Within this framework, emission reductions from deforestation and forest degradation play a central role, with the Forest Reference Level (FRL) serving as the baseline for measuring performance and allocating incentives.

The FRL represents a historical benchmark against which emission reductions are assessed. Indonesia's FRL for 2022 adopts a reference period that typically spans 10 years, consistent with international practice. While this approach enhances transparency and comparability, it also introduces structural limitations. Regions with a history of high deforestation tend to generate larger reference emissions, creating greater potential for crediting reductions.

This tension raises important questions about the equity and effectiveness of carbon trading systems that rely solely on historical emissions data. In the context of REDD+, previous studies highlight that successful mitigation outcomes depend not only on biophysical factors but also on governance capacity, institutional coordination, and stakeholder collaboration (Teimoory et al. 2022; Adame et al. 2024). However, empirical evidence suggests that sub-national implementation remains uneven. Weak actor networks, fragmented institutional arrangements, and limited awareness of deforestation risks continue to constrain effective REDD+ implementation in several regions (Sanders et al. 2017; Velasco et al. 2023).

Central Kalimantan provides an illustrative case. Studies indicate that halting further forest conversion for oil palm could reduce emissions by approximately 22% relative to baseline levels (Irawan et al. 2019). Nevertheless, the governance dynamics of REDD+ in the province reveal challenges in establishing robust, coordinated institutional frameworks. These challenges are further complicated by increasing climate variability and extreme events, which add uncertainty to forest management and mitigation planning (Blöschl et al. 2019; Balch et al. 2020; Rusca 2024).

At the local scale, conservation areas such as Salat Island provide important insights into how emission reference design affects incentive outcomes, which, in turn, may influence the effectiveness of the climate change mitigation financing mechanism (Sheriffdeen et al. 2020). Salat Island is a conservation area managed collaboratively by PT Mitra Mendawai Sejati and the Borneo Orangutan Survival Foundation, primarily for pre-release orangutan habitat. Conservation success in such areas helps maintain low deforestation rates, yet it may paradoxically limit access to carbon trading incentives when historical emissions are used as the primary reference. This situation illustrates a broader policy dilemma: effective conservation may be under-rewarded when reference systems prioritize past emissions over current performance and future risk.

Parallel to these governance challenges, a growing body of literature emphasizes the role of community participation and community forestry in achieving sustainable forest management and climate mitigation goals (Hovis et al. 2022; Di Girolami et al. 2023; González-Torres et al. 2024). Community-managed forests have demonstrated potential to deliver environmental services and support climate-smart forestry transitions, yet their contributions are often undervalued within formal incentive mechanisms (Rossita et al. 2021; Pagot and Gatto 2024). This gap further underscores the need for incentive frameworks that recognize diverse pathways to emission reduction and forest conservation.

Despite extensive research on REDD+ implementation and carbon governance, limited attention has been given to how the design of emission reference levels influences incentive distribution across regions with contrasting deforestation histories. In particular, there is a lack of empirical analysis comparing site-level and jurisdictional reference emissions and examining how alternative reference approaches could improve incentive compatibility for regions with historically low emissions, such as Papua Island.

This study analyzes the implications of emission reference levels for carbon trading incentives in Indonesia's forestry sector. Specifically, it compares site-level reference emissions (Salat Island) with jurisdictional-level emissions (Pulang Pisau District) using primary data, and assesses emission reference patterns for Papua Island relative to other major islands in Indonesia using secondary data. The study seeks to identify alternative emission reference options that enhance equity and effectiveness in incentive allocation while maintaining environmental integrity within Indonesia's carbon trading framework. Accordingly, this study hypothesizes that the use of uniform, historically based emission reference levels results in unequal carbon-trading incentives across regions with differing deforestation histories, and that adaptive reference approaches can improve equity without compromising environmental integrity.

MATERIALS AND METHODS

Study area

The study took place on Salat Island, located on the Kahayan River. This island is part of the Pilang Village administration, within the Jabiren Raya Sub-district of Pulang Pisau District, Central Kalimantan Province, Indonesia, at coordinates 114°12'8.810"E and 2°23'50.425"S (Figure 1).

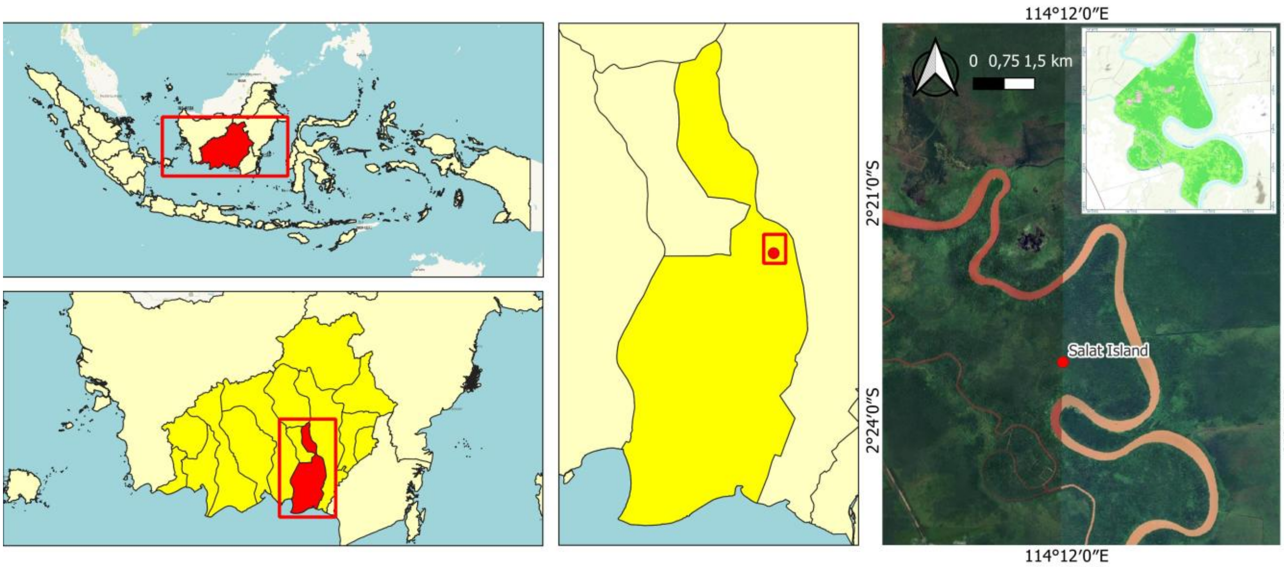

Figure 1. Salat Island emission reference study location in Pilang Village, Jabiren Raya Sub-district, Pulang Pisau District, Central Kalimantan Province, Indonesia

The elevation at the study location ranges from 0 to 31 meters above sea level (Figure 2), and rainfall ranges from 2500 to 3000 mm/year (Figure 3). The dominant types of trees found include: *resak* (*Vatica rassak*), *latak manuk* (*Dysoxylum* sp.), *madang* (*Alseodaphne macrocarpa*), *kadamba* (*Anthocephalus cadamba*), *pohon darah* (*Nephelium criopetalum*), and *rengas* (*Gluta renghas*). This location was chosen because it has unique conditions: it is on a small island surrounded by a fairly wide river. The existence of a small island separated from the mainland has made it a pre-release site for orangutans, covering 2,134.62 ha. The vegetation cover on Salat Island comprises sparse and dense secondary forests, providing suitable conditions for orangutans prior to their return to their natural habitat.

Procedures

Land cover classification and sampling design

In the Forest Reference Level document (Ruslono et al. 2022), Indonesia's land is classified into 23 classes. There are 23 classifications in Indonesia, indicating that a more detailed classification has been implemented at the national level. The classification of management unit locations can be refined, but it still refers to the existing classification in the national system.

Land cover classification analysis in the study area was conducted using Sentinel-2 imagery from 2023, PT Sawit Sumbermas Sarana documents from 2023, Indonesian Topographic Data from 2023, and Google Satellite Basecamp from 2023. The land-cover classification was based on the 23 classes defined by FRL (Ruslono et al. 2022). Furthermore, area analysis and calculations were performed for each land-cover class. The sampling design used was stratified systematic sampling with a random start. The error in this study was 10%. This has met SNI 7724-2019, which requires a maximum error of 20%.

Formula for determining sample size

The number of plots to be sampled is determined by conducting a pre-assessment inventory. Based on the results of this pre-inventory assessment, a 90% confidence level and a 10% error rate are used to determine the number of plot samples required in accordance with international standards. The formula used is the one recommended by the UNFCCC, and it has been incorporated into the Winrock Calculator by Walker et al. (2014).

Determination of the sample plot in this research was carried out using systematic random sampling. The first step is to classify land cover in the study area using analyses of 2022 Sentinel-2 Imagery, 2023 PT MMS Documents, 2023 Indonesian Landform Data, 2023 Ministry of Environment and Forest (MoEF) data, and 2023 Google Satellite Basecamp imagery. Based on the land cover mapping results, sample plots are randomly selected to represent each land cover.

Data collection follows SNI 7724:2019. The plot includes subplots to collect data on trees with diameters greater than 20 cm (section D, with a radius of 11.29 meters). Subplot for pile level (10≤diameter<20, section C with radius 5.64 meters). Subplot for stake levels with intermediate diameters (2≤diameter<10, section B with radius 2.82 meters). Subplot for seedlings (plants <2 cm diameter, section A with a radius of 1.13 meters) (Figure 4).

Field measurements

Field data are collected at the plot locations specified in the sampling design. Researchers must locate the designated plot points using GPS. Furthermore, the number of survey plots selected in the study must equal the minimum number of plots required by the sample-size formula.

Data analysis

Above Ground Biomass (AGB) and Below Ground Biomass (BGB)

Biomass of litter, seedlings, and understory was measured in the laboratory using furnace-dry weight parameters in accordance with SNI 7724:2019 and C-organic parameters by gravimetric analysis. Other AGB parameters, namely sapling, pole, and tree-level plants, were measured in accordance with SNI 7724:2019.

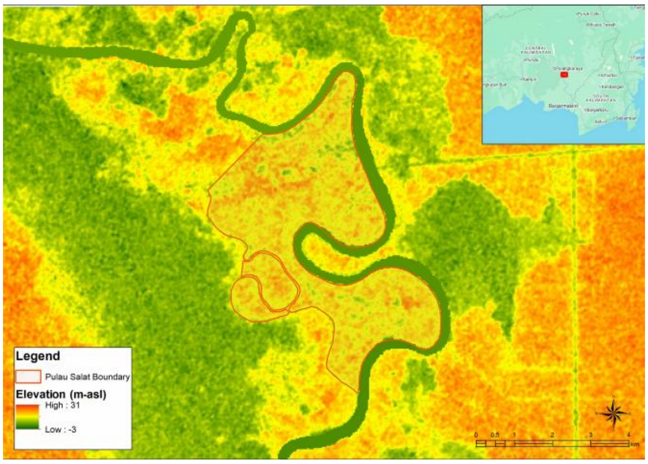

Figure 2. The elevation of the study location

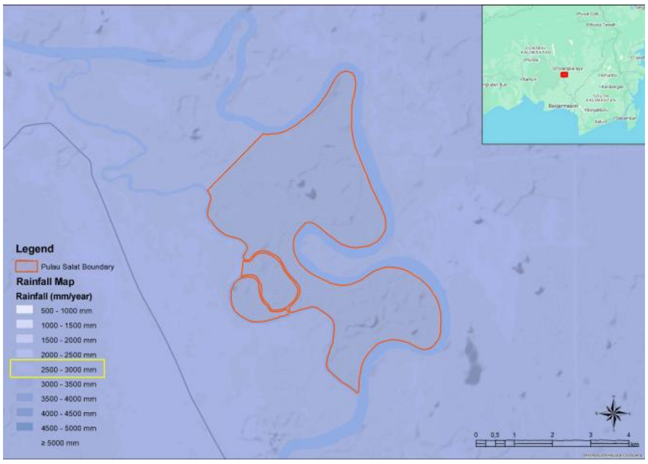

Figure 3. Rainfall at the study location

Data on measurements of saplings, poles, and trees on dry land are converted to biomass using the formula of Ketterings et al. (2001).

$B = 0.11\ \rho D^{2,62}$

Where:

B: Tree biomass (kg)

ρ: Density

D: Tree diameter (measured 1.3 m from the ground).

Biomass values in saplings, poles, and trees for each type of land cover are then converted using the following formula:

Wood carbon = %Carbon x B

Where:

% Carbon: Percentage of organic carbon

B: Tree biomass in tons/ha

Wood density information was obtained from the Indonesian Timber Atlas, Volumes 1 and 2, and from ICRAF. Biomass values were obtained using allometric formulas for each type of sapling, pole, and tree in each land cover classification class. Carbon values were obtained by multiplying the biomass value for each sapling, pole, and tree by the carbon percentage. In SNI 7724:2019, the percentage of carbon in wood, litter, and dead wood is 47%. For this calculation example, we use the carbon percentage in wood as stated in SNI 47%.

Forest Reference Level (FRL) Analysis

In the 2nd FRL document for 2022, the reference for Indonesian emissions used is 2006–2020. Decree of the Director General of Climate Change Control (CCC) No. 30 of 2023 states that the emission reference period is between 5 and 10 years (Direktorat Inventarisasi Gas Rumah Kaca dan Monitoring Pelaporan Verifikasi 2023). Thus, if emission-reduction activities are planned in the coming years, an emission reference study in accordance with the FRL is necessary.

To determine reference emission values, the necessary steps include analyzing the land-cover classification, calculating carbon for each land-cover class, and obtaining the emission factor for each class. The most appropriate emission factor for calculating reference emission values was the specific emission factor for the study location (Tier 3). In this study, reference emission calculations were performed using either primary data or emission factors specific to Salat Island. This emission factor is used to calculate potential carbon stocks for 2006, 2012, 2015, and 2022. Changes in carbon potential from 2006 to 2022 are used to estimate trends and future carbon emissions. In this study, emission references are calculated using the average emission storage loss for the period 2006-2022 (Figure 5).

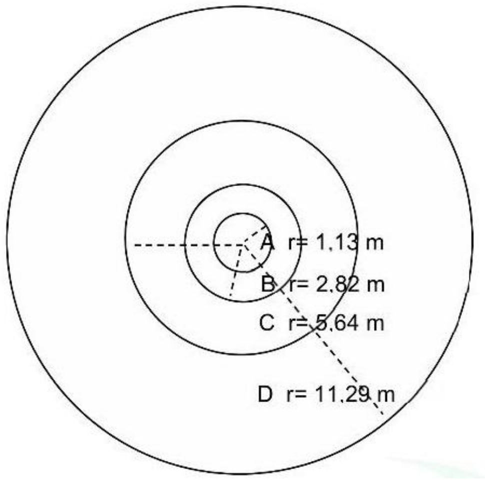

Figure 4. Sketch of forest carbon data collection plot

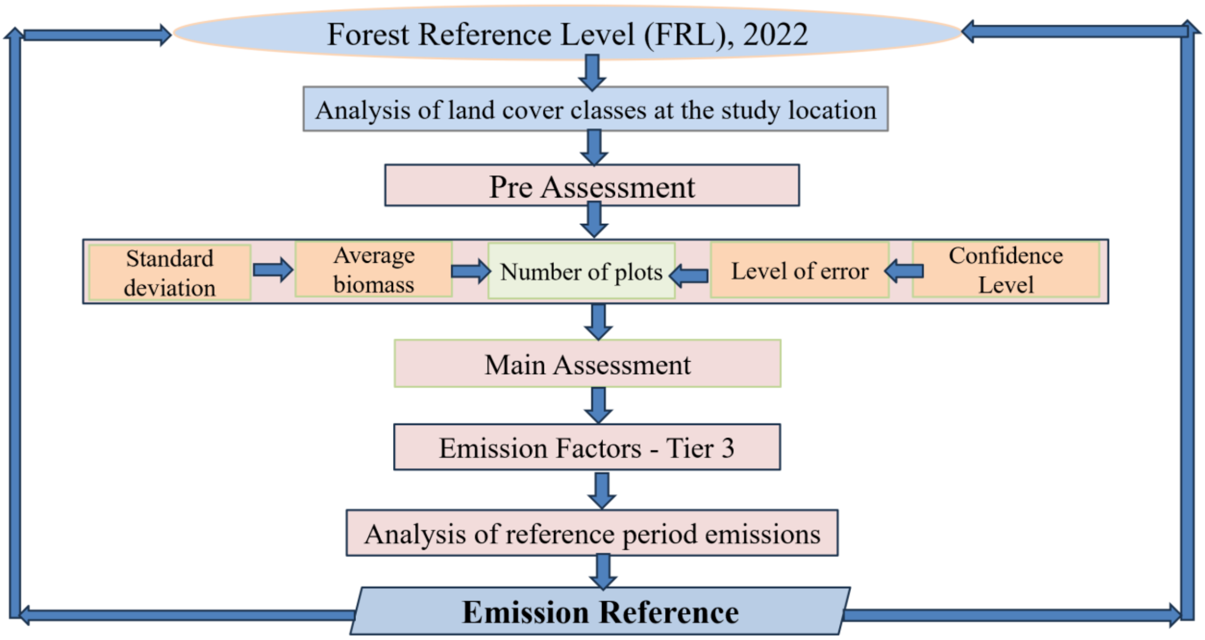

Figure 5. Flow chart for determining emission references

RESULTS AND DISCUSSION

Land cover map and sampling plots

Industrialized countries have made significant contributions to research on deforestation and land-cover change (Afuye et al. 2024). Deforestation and land degradation are driven by multiple factors, including changes in land cover, climate change, poor land management, and population growth (Solomon et al. 2024). Based on land cover analysis carried out from Landsat-8 OLI, Sentinel-2A, and Sentinel-2B imagery, it is known that in 2022, land cover in the PT MMS Salat Island area consisted of dense secondary forest 1,253.75 ha, sparse secondary forest 805.90 ha, open land 39.47 ha, and water bodies 35.50 ha (Table 1). A pre-assessment is conducted to determine the total number of plots required for the carbon calculation study. The number of sampling plots for Salat Island was 32 (Table S1).

Emission factor of dense secondary forest

There were 24 dense secondary forest sampling plots on Salat Island. The carbon stock potential of the dense secondary forest soil on Salat Island is highly variable. The potential carbon stock (above-ground biomass, below-ground biomass, litter, and dead wood) in the 24 plots ranges from 57.41 to 187.56 tons C/ha, with an average of 102.47 tons C/ha and a standard deviation of 35.18 (Figure 6). The large variation among plots was attributable to the number of trees per plot, which ranged from 4 to 23. This area is a natural secondary forest, with illegal logging interfering, resulting in an uneven, random distribution of trees. Eight sparse secondary forest sampling plots were established on Salat Island. The value of carbon stocks in Salat Island's sparse secondary forest soil ranges from 40.38 to 95.50 tons C/ha (Figure S1).

Land cover change of Salat Island

Land cover analysis of the PT MMS Salat Island forest was conducted in 2006, 2012, 2015, and 2022 (Figure 7). At this stage, the various data used are Landsat-5 TM, Landsat-7 TM, Landsat-8 OLI, Sentinel 2A and 2B imagery, PT MMS spatial data for 2023, Indonesian Earth Shape Data for 2023, thematic geospatial information on the cover of the MoEF land in 2006-2023, and Google Satellite Basemap in 2023.

The land cover of PT MMS Salat Island in 2006 consisted mainly of dense secondary forest (1,592.57 ha) and sparse secondary forest (493.29 ha). A reduction in dense secondary forest was observed from 2009 to 1,479.49 ha, while sparse secondary forest increased by 591.54 ha. In 2012, dense secondary forests also decreased to 1,403.69 ha, while sparse secondary forests increased by 650.84 ha. By 2015, dense secondary forest decreased further to 1,396.20 ha, and the increase in sparse secondary forest was relatively small, reaching 677.69 ha. Results from the land-cover change analysis for 2006-2022 indicate that the area of dense secondary forests decreased, while the area of sparse secondary forests increased. However, the increase in sparse secondary forests was insufficient to offset the decline in dense secondary forests. The analysis identified four land-cover types on Salat Island: dense secondary dry land forest, sparse secondary dry land forest, open land, and water bodies (Figure 8).

Table 1. Land cover changes for the period 2006-2022

Land cover	Area (Ha)							
	2006	2009	2012	2015	2018	2020	2021	2022
Dense Secondary Forest	1,592.57	1,479.49	1,403.69	1,396.20	1,313.35	1,264.17	1,259.83	1,253.75
Rare Secondary Forest	493.29	591.54	650.84	677.69	754.58	759.39	798.96	805.90
Open Land	10.43	10.43	10.43	21.77	28.13	44.78	36.89	39.47
Open Water	38.33	53.17	69.67	38.97	38.56	66.28	38.94	35.50
Total (Ha)	2,134.62	2,134.62	2,134.62	2,134.62	2,134.62	2,134.62	2,134.62	2,134.62

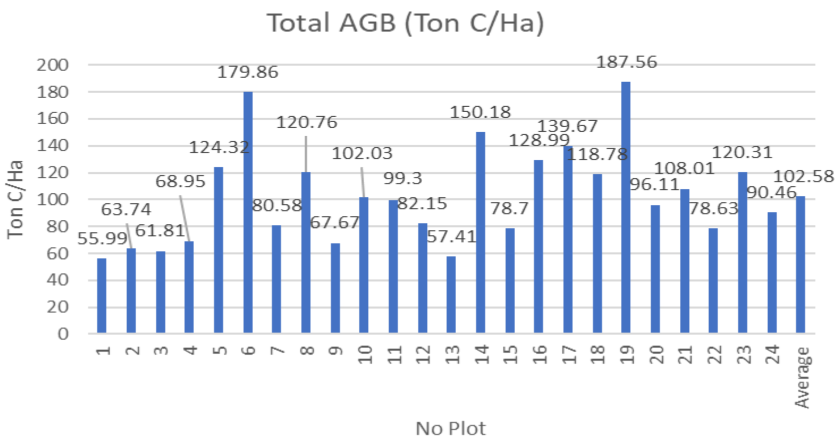

Figure 6. Dense secondary forest emission factors at Pulau Salat, Pulang Pisau District, Central Kalimantan Province, Indonesia, each plot

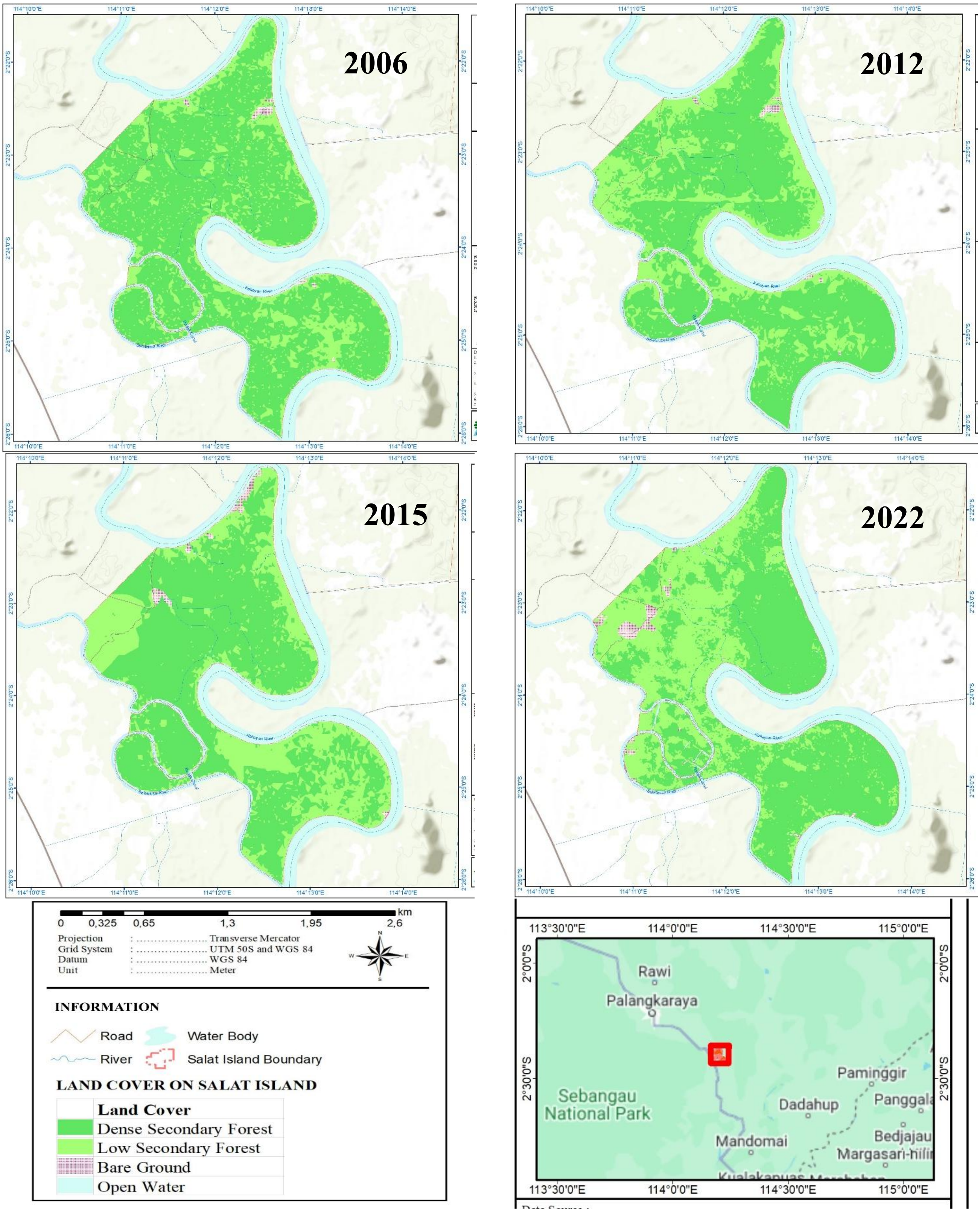

Figure 7. Land cover changes from 2006 to 2022

The average annual deforestation rate for 2006-2020 was 1.29%. It is small relative to deforestation at the subnational scale, but it represents a success in orangutan conservation on Salat Island. Purnomo et al. (2023) said legal and illegal deforestation contributed to significant forest loss. About 80% of world deforestation is caused by agricultural activities (Kissinger et al. 2012), and deforestation of tropical moist forests increases carbon emissions (Vijay et al. 2016). In a study by Biadgligne et al. (2022) on community forests in Ethiopia, the annual deforestation rate from 2010 to 2020 was 1.87%. The conditions that threaten forests in Indonesia vary by island.

Salat Island emission reference analysis

Based on the results of actual carbon uptake calculations and land cover change analysis, reference emissions on land cover on Salat Island are identified. The emission factor for dense secondary dry forest land cover is 102.58 tons C/ha or 376.13 tons CO_2-e per ha, and the rare secondary dry forest land cover is 65.58 tons C/ha or 240.46 tons CO_2-e per ha. Figure 8 shows reference emissions from 2006 to 2022 on vegetated land cover.

The results show deforestation in dense, dry-land secondary forest from 2006 to 2022, resulting in carbon (C) emissions of 34,755.74 tons and CO_2-e emissions of 127,437.71 tons. In contrast, secondary dry-land forest cover rarely saw a reduction in emissions of 20,500.40 tons C or 75,168.14 tons CO_2-e (Figure 8). Salat Island's potential emission storage in 2006 was 717,624.21 tons of CO_2e, and in 2022 it was 665,354.64 tons of CO_2e. Emissions for the 2006 – 2022 period are 52,269.57 tonnes of CO_2e with reference emissions of 3,266.85 tonnes CO_2e per year or reference emissions of 0.46% per year (Table 2).

Deforestation on Salat Island, although relatively small compared with other regions, remains a significant concern. The majority of deforestation around Salat Island is driven by agricultural and plantation activities, particularly for oil palm plantations. According to Nurrochmat et al. (2020), lands allocated for oil palm plantations in Central Kalimantan are primarily derived from former forest zones. In addition to oil palm plantations, other agricultural commodities, such as rubber, paddy rice, and food crops, contribute to deforestation. To address this issue, it is crucial to align interests with real action (Ferrante and Mouysset 2024). Deforestation, regardless of its scale, will cause land damage in the short and long term. Soil, which provides essential ecosystem services such as nutrient cycling and water regulation that sustain life on land (Sinitambirivoutin et al. 2024), is particularly vulnerable to these changes.

Table 2. Annual reference tabulation

Land cover	Emission reference 16 years (Ton CO_2e)	Emission/Year (Ton CO_2e)	Emission reference/Year (%)
Dense Secondary Forest	127,437.71	7,964.86	
Rare Secondary Forest	-75,168.14	-4,698.01	
Open Land	0.00	0.00	
Open Water	0.00	0.00	
Emission Reference (Ton CO_2-e)	52,269.57	3,266.85	0.46

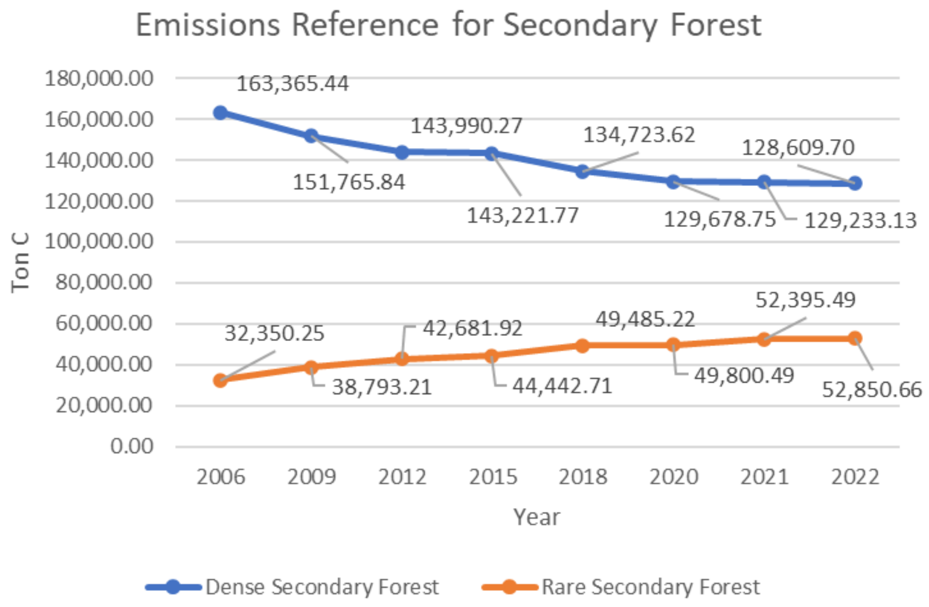

Figure 8. Reference emissions for 2006-2022 (Tons CO_2-e) on Salat Island, Central Kalimantan Province, Indonesia

Proxy analysis of sub-national land cover change

Reducing deforestation and forest degradation emissions, and enhancing forest carbon stocks (REDD+) was expected to be a quick, cheap, and easy way to lessen the climate impacts of land-use and land-cover change (Angelsen et al. 2018). Proxy analysis was used to assess changes in Salat Island's land cover relative to those in the Pulang Pisau District subnational area, Central Kalimantan

Province, period 2006-2022 (Figure 9). It is necessary to compare land-cover changes on Salat Island in the absence of orangutan conservation activities. The results show that for the 2009-2022 period in the sub-national Secondary Dry Forest area (Pulang Pisau District), there was a forest loss of around 18 million Tons of CO_2-e with an average annual emission reference of 1.13 million tons of CO_2-e per year or an emission reference of around 1.06% per year (Figure 10).

Changes in land cover in Pulang Pisau District are generally greater than changes in land cover in the Salat Island area. This could mean that the orangutan conservation program on Salat Island has been successful. The potential impact of this success on subnational-level emission references in the Pulang Pisau District is significant and warrants further study to inform these references. Model approaches that compare project-site emissions with subnational reference emissions need to be considered. At the study site, this means that, in the absence of orangutan conservation projects, the emission reference for Salat Island would be the district average.

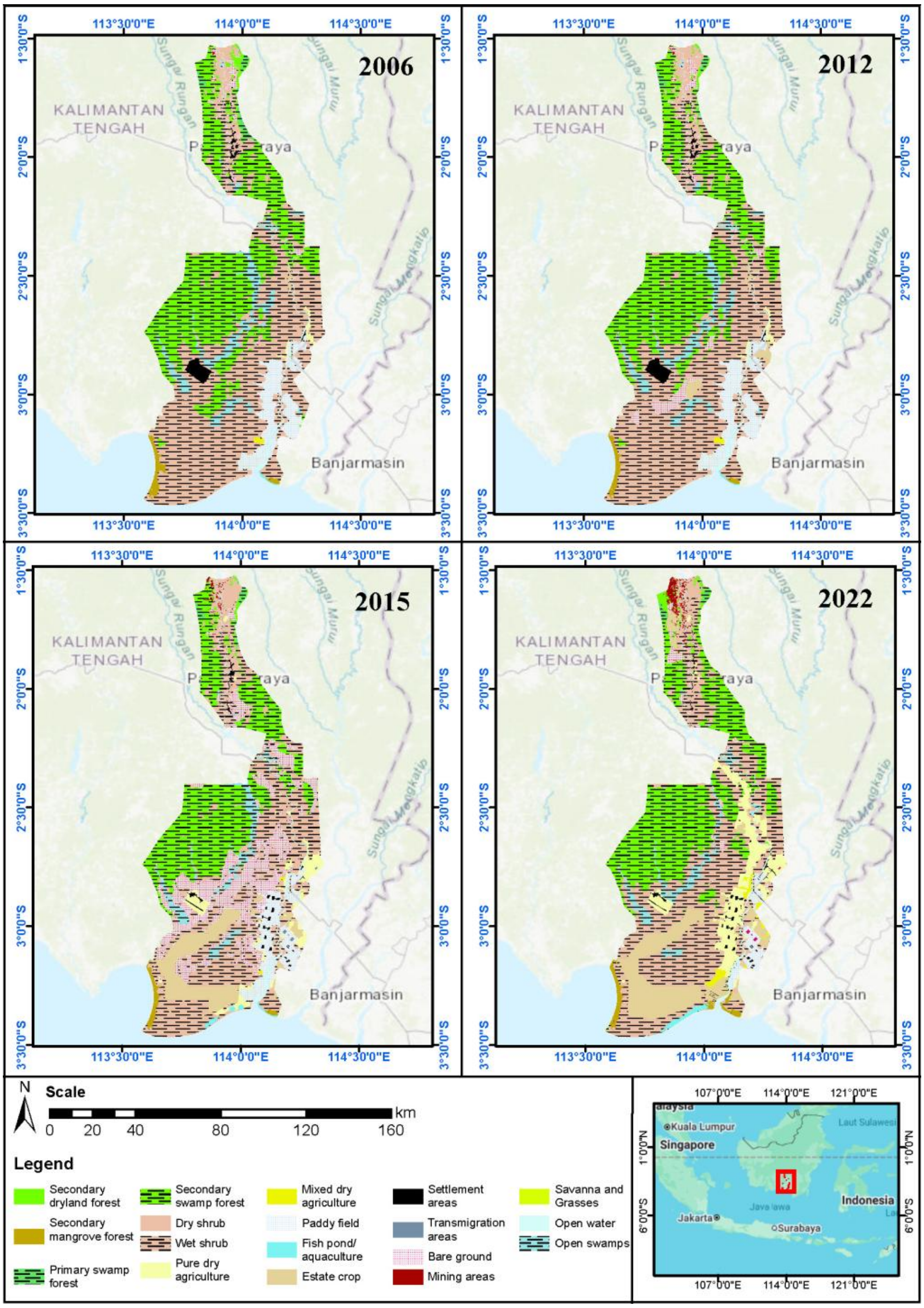

Figure 9. Land cover of Pulang Pisau District, Central Kalimantan Province, Indonesia

Comparison of emission references for Papua Island with other islands in Indonesia

The condition of Salat Island, Pulang Pisau District, Central Kalimantan Province, is a small reflection of Indonesia. Other islands experience similar situations, such as Salat Island. Papua Island is a topic most often debated in Indonesian scientific forums. Papua Island has extensive forests with a very low potential for deforestation and forest degradation. Under these conditions, the potential for Papua Island to receive carbon trading incentives based on emissions references is minimal. It raises the question of whether Papua must engage in deforestation and forest degradation to receive carbon trading incentives.

Analysis of the Global Forest Change Dataset, processed in Google Earth Engine, indicates that forest loss in Papua is relatively low compared with other provinces in Indonesia. In Guyana, they have corrected the use of past deforestation values as the basis for calculating emission-reduction performance. The reference level for deforestation in Guyana agreed upon in the REDD+ program between Guyana and Norway is 0.275% per year, far above Guyana's historical average of 0.02% (Hook and Laing 2022). According to the Sandker et al. (2014), Guyana has extensive forests, and the average deforestation for the period 2000-2009 was very low, namely 0.03%. Meanwhile, the average deforestation rate in developing countries during 2005-2009 was approximately 0.52%. Thus, Guyana has a lower average deforestation rate than other developing countries. Guyana has an average deforestation rate of approximately 0.275%, comparable to that of other developing countries, for reference regarding emissions.

Comparison of deforestation as basic data for calculating reference emissions (Table 3). The FRL document published in 2022, for the reference period 2006–2020, describes deforestation across Indonesia. The highest deforestation is on Java Island, followed by Sumatra Island, and the lowest is on Papua Island. Papua Island, for 2006-2020, saw an increase in forest area (Table 3).

Policy constraints

The policy obstacle to obtaining incentives under carbon trading on low-emission islands, such as Papua, is that the current method of calculating emission references is applied to all locations. In the future, distinctions should be made in the use of emission references between regions with high and low emission rates. The use of a single emission reference calculation method to assess mitigation actions will, across Papua New Guinea, make it difficult for jurisdictions, forestry companies, and social forestry, including customary forests, to obtain carbon trading incentives. It's of utmost importance to implement a community-based management agenda, as it is the key to incentivizing local people to protect their forests (Rahmani et al. 2022; Rochmayanto et al. 2023). Collaboration between the private sector, local communities, and non-governmental organizations can create the conditions necessary for sustainable agricultural production without destroying forests (Rahman et al. 2025).

Table 3. Comparison of deforestation on islands in Indonesia for the period 2006-2020

Island	Deforestation for 14 Years (ha)	Deforestation rate per year (ha)	%
Sumatera	2,020,908.30	144,350.59	0.90
Kalimantan	2,699,757.80	192,839.84	0.65
Sulawesi	450,097.70	32,149.84	0.33
Papua	-264,969.10	-18,926.36	-0.05
Bali and Nusa Tenggara	87,643.30	6,260.24	0.22
Maluku	67,330.90	4,809.35	0.09
Jawa	601,447.30	42,960.52	1.27
Indonesia	5,662,216.20	404,444.01	0.39

Source: Processed from FRL in 2022

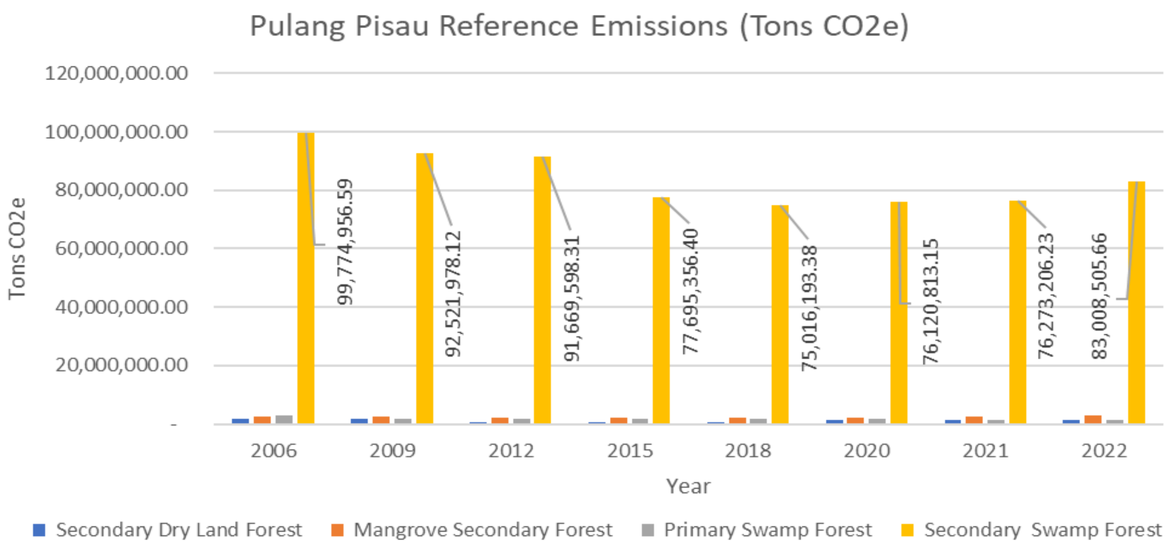

Figure 10. Reference emissions of Pulang Pisau District, Central Kalimantan Province, Indonesia, in 2006-2022

A more integrated approach to policy for controlling deforestation and mitigating climate change is needed. Implementing REDD+ effectively in Papua and Salat will require precise measurements of carbon stocks and the impacts of implemented policies, including emissions levels and reference generation. Collaboration between the government, international organizations, and local communities must be the foundation for implementing this policy (Nomura et al. 2019). Policies that facilitate indigenous peoples' land rights and include them in forest resource management can encourage their participation in sustainable practices. Encouraging private and community participation in implementing mitigation actions, including in Papua, requires policies that account for specific contexts, particularly on Papua Island and other typical islands.

Fair policy for Salat Island and Papua

Theoretically, there are three baselines for establishing emission references: project-level, subnational, and national. Emission-reduction activities under the Ministerial Regulation of the Ministry of Environment and Forestry 21/2022 may be undertaken by four parties: ministries and institutions, regional governments, business actors, and the community. Four scenarios can be implemented to ensure fairness in carbon trading across regions with low reference emissions. This approach can be applied to Salat Island, Papua, or other areas with healthy forests and low-emission references.

Table 4 shows that during 2006-2020, all Indonesian islands experienced deforestation, resulting in a loss of carbon storage, except for Papua Island. The island with the highest percentage loss of emissions is Java. During this period, Papua Island experienced an increase in forest cover, resulting in greater carbon storage. If this trend continues unchecked, Indonesia will continue to lose forests, thereby threatening ecosystem sustainability and adversely affecting communities that depend on forests for their livelihoods. Empirical and objective evidence will be more convincing to the parties, particularly the government. Objective evidence in the field, such as modeling, is more effective at convincing policymakers (Purwawangsa et al. 2022). Responses to the climate crisis must address the roots of the problems, as well as the uneven and combined socioecological disasters (Andreucci and Zografos 2022). Many tropical forest lands are experiencing changes; however, how these changes may affect deforestation rates remains unclear (Pacheco and Meyer 2022). According to Sharma et al. (2020), preventing deforestation is an effective strategy for mitigating the impacts of climate change.

Using the reference period 2006–2020 for Papua Island will make it difficult for the island to receive carbon trading incentives. Thus, to ensure fairness in carbon trading incentives, emission baselines for low-emission areas, including Papua Island, should be set separately from those for other islands. Four emission reference scenarios can be used for areas with good forest conditions but low emission references (Figure 11).

Figure 11 presents four emission reference scenarios for areas with low emission reference values. In the first scenario, the emission reference for Papua Island is either the average Indonesian reference or a subnational reference for smaller areas. In the second scenario, the emission reference to use is the average of the Indonesian and Papuan emission references, divided by 2. The third scenario uses 50% of Indonesia's emission reference. The fourth scenario uses 25% of Indonesia's emission reference. Across these four alternative scenarios, the baseline deforestation area in Papua is reasonable (Table 4).

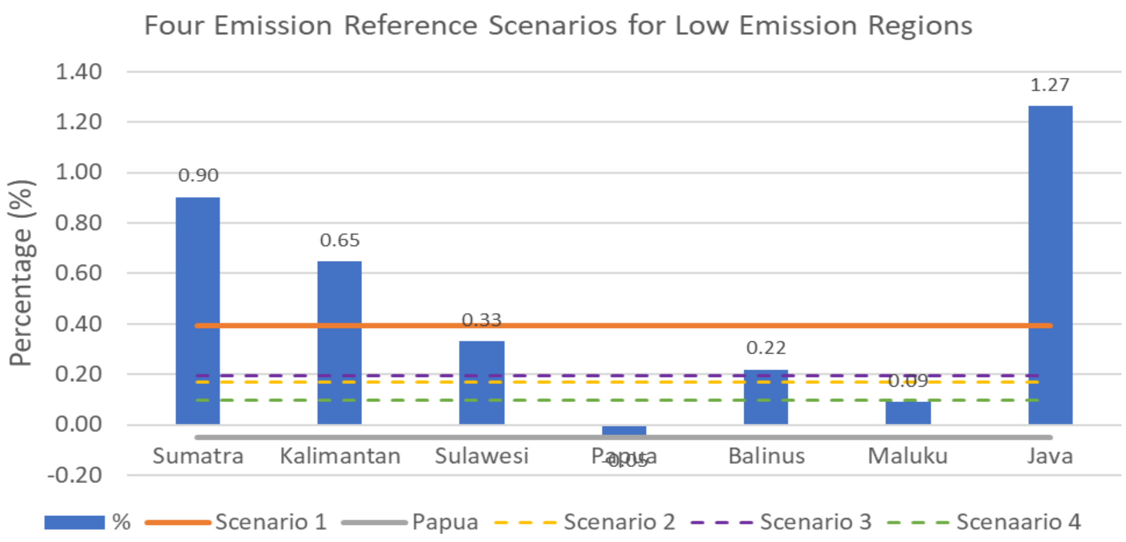

Figure 11. Four emission reference scenarios in areas with low emission references

Table 4. Area of the Papua, Indonesia, emissions reference scenario

Scenario	Alternative scenario	Percentage of scenario (%)	Papua area in 2020 (ha)	Papua reference Scenario Area (ha)
Scenario 1	Indonesian average	0.39	36,482,193.90	142,887.68
Scenario 2	(Indonesian average + Papuan average)/2	0.17	36,482,193.90	61,911.43
Scenario 3	50% of the Indonesian average	0.20	36,482,193.90	71,443.84
Scenario 4	25% of the Indonesian average	0.10	36,482,193.90	35,721.92

In one of these scenarios, low-emission reference areas will still receive fair incentives under carbon trading. Good state planning is optimal when it employs fair policies, including the use of emissions references to provide carbon-trading incentives. Sustainable forest development can be implemented effectively if a more appropriate sustainability standard is normative, reasonable, measurable, and practical (Nurrochmat et al. 2022, 2023).

Regions with primary forests generally have high carbon stocks and are likely to have endemic biodiversity. In areas that have endemic flora and fauna, it is necessary to provide incentives for non-carbon benefits. Non-carbon benefit incentives have long been discussed in scientific forums, but only a few have been implemented.

The government can implement this policy so that locations with endemic flora and fauna, even if their potential to reduce emissions is low, can receive incentive value from non-carbon benefits. Salat Island, Pulang Pisau District, Central Kalimantan Province, and Papua Island can earn incentives for non-carbon benefits. Non-carbon benefits can also mean conserving medicinal plants that benefit society. According to Nurrochmat et al. (2017), medicinal plants in the national park contribute to the park's biodiversity and provide medicinal and economic benefits to Rah communities. Local knowledge of environmental and climatic factors that influence the mortality of specific tree species is part of local diagnosis and aligns with scientific knowledge (Hammond et al. 2022; Hartmann et al. 2025).

Discussion

Incentive alignment

Carbon trading incentives have successfully encouraged many parties to participate in reducing emissions from forests and land. An important aspect of promoting sustainable land management in Papua is implementing mechanisms such as REDD+. This program provides a financial incentive to maintain forest cover and reduce carbon emissions associated with deforestation. In regions with high forest cover and low deforestation rates, such as Papua New Guinea, flexible REDD+ payment structures can respond dynamically to commodity price fluctuations that often drive deforestation. Such an adaptive approach would allow better alignment with local economic realities and could provide incentives for conservation while supporting local livelihoods (Rahmani et al. 2021; Schweikart et al. 2022).

Other incentives that will increase the REDD+ program's chances of success include international cooperation and funding. Angelsen (2017) describes how REDD+ has evolved from merely results-based payments towards more complex policies, emphasizing how bilateral aid can support emission reductions from deforestation. This strengthens the argument about the role of funding in supporting REDD+ policies.

Equity and legitimacy

Climate change affects all parties, and all parties are expected to participate in reducing future risks. The principles of equality, fairness, and openness bind the parties' participation. The party that creates the mitigation action design document must be the program proposer and have legal legitimacy. Legitimacy in the context of land management policy refers to the acceptance and support of the policy by the community and other stakeholders. Transparent and accountable implementation of REDD+ policies can strengthen their legitimacy at the local level. Disseminating clear information regarding the benefits and community participation in REDD+ projects is very important to build trust (Prasetyo and Trisnaningtyas 2025).

In addition to legitimacy within local and national policies, a climate change mitigation effort is expected to have international legitimacy. Legitimacy in international law extends beyond mere compliance with a legal framework. Legitimacy includes ethical considerations and communication practices that reflect justice, human rights, and community engagement. The dynamic nature of legitimacy, shaped by interactions between global actors and consensus within the international community, illustrates how perceptions can influence the implementation and acceptance of forest management practices. This is especially relevant when residents are affected by policies, and their participation can increase the legitimacy of conservation efforts (Vysotskyi 2024).

Scalability

One important aspect of REDD+ scalability is the extent to which local governance structures are integrated into national policies. Globally, effective REDD+ implementation has shown that successful programs often depend on community and local stakeholder involvement in decision-making. Community involvement in REDD+ activities is relatively more likely to guarantee the program's long-term sustainability. Evidence from Southwestern Ghana suggests that local adaptation to REDD+ legislation, when combined with international resources, facilitates adaptation to local needs, thereby enhancing the framework's scalability. This suggests that bottom-up governance can complement national strategies, leading to broader acceptance and integration of REDD+ principles (den Besten et al. 2019).

Successful land management policies to prevent deforestation under REDD+ require strong institutional support. The formation of a strong institution typically begins with the parties' collaboration, including the determination of a long-term vision and the programs to be implemented. Informal institutions in natural resource management help fill the void left by formal institutions, which are often less effective. This is particularly relevant in the forest land context, where the presence of local institutions can expedite the implementation of REDD+ policies. By empowering local groups, policies can be more easily adapted and accepted by local communities (Rifandini 2022)

Many significant challenges must be faced in deforestation governance, especially when mitigation action areas border or conflict with communities. Policies often set ambitious targets for stopping deforestation without providing sufficient detail on how to achieve emissions reductions from deforestation. This situation often confuses implementers of actions at lower levels. This shows a lack of specific, measurable, achievable, realistic, and timely policy formulation, which is very important to ensure long-term effects in managing deforestation (Wahyuni and Suranto 2021).

Governance lessons

One significant lesson from climate change policy is the substantial gap in human resources between the central and regional levels, particularly regarding emissions reference issues. With the legalization of international carbon trading in 2025, the Indonesian government is tasked with promoting stakeholder participation. The central government's responsibility to stimulate active involvement from local governments, the private sector, and the community is crucial in achieving the NDC target. The government's establishment of emission references at the project, location, district, or provincial jurisdictional scale is a key strategy. Many project-scale locations have effectively preserved forests from deforestation and degradation. However, this cannot be considered a mitigation effort because the emissions risk is relatively low, typically managed by small-scale communities. It is expected that small companies and farmer cooperatives will be most affected by future climate risks (Paitan et al. 2024).

The human resource capacity gap differs between the center, provinces, and districts. Providing an understanding of emission references requires greater emphasis. The forests on Papua Island are still extensive, but the risk of emissions is low. These conditions make parties interested in reducing emissions reluctant to carry out mitigation actions in Papua. The Papua Regional Government frequently protests the provision of carbon trading incentives, arguing that deforestation must occur first and that only areas with a high risk of deforestation and forest degradation are attractive to carbon trading businesses.

The government needs to establish regulations governing fair incentives in carbon trading. Legal protection is often a crucial factor in a program's success (Gifford et al. 2024). According to Purwawangsa et al. (2022), science will be more effective and have a greater impact if it aligns with societal or policy-maker interests. Regulations regarding emission references may combine study-area, subnational, and national-level references. Improving the capacity of human resources within government institutions and project proponents regarding emissions reference is essential. Strong resource support from central and regional governments is crucial for accelerating the implementation of mitigation actions to achieve the NDC.

In conclusion, this study demonstrates that reference emission levels and deforestation dynamics vary considerably across regions in Indonesia, with several islands exhibiting relatively low historical emission records. Quantitatively, Salat Island exhibited total reference emissions of 52,269.57 t CO_2e for 2006–2022, equivalent to 3,266.85 t CO_2e yr^{-1} or 0.46% yr^{-1}, substantially lower than the sub-national reference for Pulang Pisau District (≈1.06% yr^{-1}). Such conditions have implications for the limited access these regions have to incentives under carbon trading mechanisms. These regional disparities indicate that a uniform approach to establishing reference emission levels may yield unequal outcomes across regions. To address this imbalance, the study proposes four alternative emission reference scenarios for low-emission regions, based on national averages, sub-national benchmarks, and proportional reference adjustments. These scenarios provide more equitable baselines while maintaining methodological consistency with the Forest Reference Level (FRL) system. Overall, the findings highlight the need for a flexible and regionally differentiated emission reference design to ensure fairness, incentive compatibility, and environmental integrity within Indonesia’s forestry carbon trading mechanism.

Based on the findings of this study, policy-makers are encouraged to adopt a more flexible and regionally sensitive framework for setting reference emission levels within Indonesia's carbon trading system. National regulations should permit the use of alternative reference emission scenarios for regions with low historical emissions, including small-area subnational benchmarks and proportional adjustments derived from national reference values. Strengthening data availability, transparency, and technical guidance at the subnational level is also essential to ensure consistent implementation and to enable equitable access to carbon market incentives across all islands. This study is limited by its reliance on historical land-cover data (2006–2020) and does not explicitly incorporate future deforestation risk, governance dynamics, or market behavior. In addition, the proposed reference scenarios were not tested against actual carbon market transactions. Future research should integrate risk-adjusted reference levels, scenario-based modeling, and pilot implementation studies using primary data from each province, particularly in low-emission regions such as

Papua, to validate the effectiveness of adaptive emission reference frameworks in practice.

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Table S1. Distribution plot of biomass data collection

No	Land cover	Area (ha)	Plots
1	Dense Secondary Forest	1,253.75	24
2	Rare Secondary Forest	805.90	8
Total			32

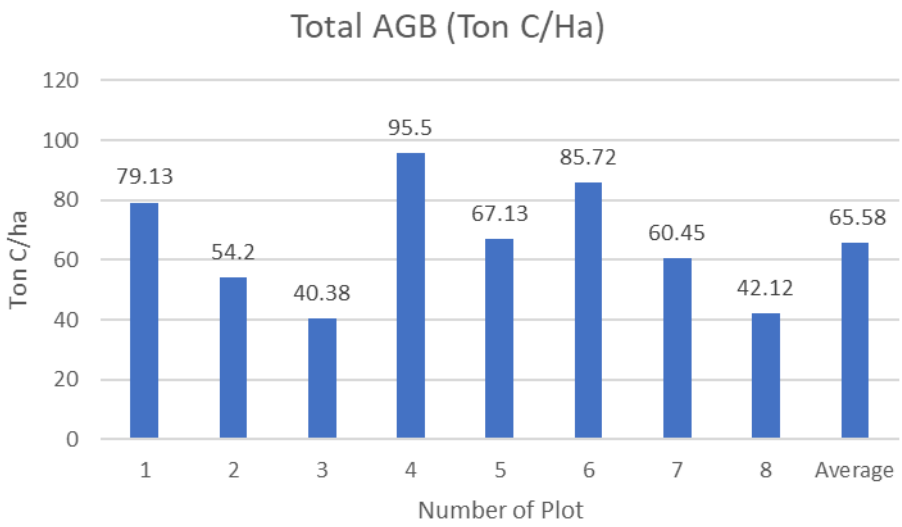

Figure S1. Emission factors for rare secondary forests on Salat Island, Pulang Pisau District, Central Kalimantan Province, Indonesia