Submission by Indonesia

NATIONAL FOREST REFERENCE LEVEL FOR DEFORESTATION, FOREST DEGRADATION, AND ENHANCEMENT OF FOREST CARBON STOCK

In the Context of Decision 12/CP.17 para 12 UNFCCC

(Encourages developing country Party to update the forest reference emission level and/or forest reference level periodically)

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Preface

Indonesia is one of the countries with the most extensive forest in the world., which provides home for high levels of biodiversity, serves environmental services as well as socio-economic benefits for the past, current and future generations. Sound management of remaining forests for economic purposes and biodiversity conservation are keys to the sustainable use of natural forest resources. Our efforts in protecting the remaining high conservation value forests and better managing the production forests yielded tangible results of a reduction of deforestation and forest degradation in Indonesia.

Indonesia's commitment to reducing greenhouse gas (GHG) emissions is stated in Indonesia's Nationally Determined Contribution (NDC) which has been submitted to UNFCCC. Compared to the business as usual (BAU) scenario in 2030, Indonesia aim to reduce the emission level by 29% on national resources or up to 41% with international support. The forestry sector shares the largest contribution to the emission reduction target, i.e., 17.2% using own resources and 24.1% with international supports. Reducing emissions from deforestation and forest degradation also known as REDD+, contributes greatly to reducing GHG emissions in the forestry sector. To achieve this fairly large forestry sector target, Indonesia undertakes various mitigation actions through GHG emission reduction activities in the forestry sector, particularly through REDD+ implementation.

Following the Warsaw Framework, parties which are willing to participate in the implementation of REDD+ need to develop the REDD+ baseline or known as forest reference emission level/forest reference level (FREL/FRL). FREL/FRL is one of the REDD+ requirements used as a reference in measuring the performance of the successful implementation of REDD+. Under the mandate of the UNFCCC COP in Decision 12/CP.17 paragraph 12, FREL/FRL needs to be updated periodically considering scientific developments, changing emission trends, as well as any modification to the scope and methodology. FREL/FRL submitted to the UNFCCC will be verified through a technical assessment process by the experts facilitated by the UNFCCC Secretariat.

The first Indonesian FREL (1st FREL) has gone through a technical assessment process in 2016 and has been legally used as a reference in measuring REDD+ performance to obtain Result Based Payments (RBP) for the period 2013 – 2020. The 1st National FREL includes 2 activities, namely deforestation and forest degradation, including the decomposition of peat in areas experiencing deforestation and forest degradation.

Most of improvement plan in the 1st National FREL has been implemented in this submission. New data, improved methodology and broader scope have been integrated into this update.

Several updates presents in the 2nd National FRL document, including:

a. REDD+ activities and emissions are taken into account include deforestation, forest degradation and enhancement of forest carbon stock, decomposition of peat, fires (peat soil and biomass) in areas experiencing deforestation or forest degradation, and emissions from conversion of mangrove forests into cultivated areas.
b. Inclusion of all carbon pools (aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon), although not for all REDD+ activities.
c. The inclusion of non-CO_2 emissions (CH_4 and N_2O) from forest and land fire activities in areas experiencing deforestation or forest degradation.
d. Application of net emission approach, instead of gross emission.
e. Utilization of tier 2 emission factors for peat decomposition, peat fires and mangrove conversion.
f. Applying adjusted areas for activity data using sample-based area estimation following methods suggested by Olofsson et.al, 2014.
g. Improvements in the uncertainty calculation using the Monte Carlo Simulation.

This 2nd National FRL document can be used as a reference in measuring the performance of National REDD+ implementation for the period 2021 – 2030. We would like to express our gratitude and high appreciation to the Indonesian FRL Team for their contribution in devoting thoughts, energy, time, and resources in the preparation of the 2nd National FRL. We also thank the assessment team who conducted the technical assessment facilitated by the UNFCCC secretariat.

Thank you.

Foreword

The Conference of Party (COP) under the United Nations Framework Convention on Climate Change (UNFCCC) invites developing countries to engage in Reducing Emissions from Deforestation and Forest Degradation (REDD+) activities. Indonesia accepts the invitation to voluntarily submit the proposed national forest reference emission level/forest reference level (FREL/FRL) for deforestation and forest degradation in the context of results-based payments for activities relating to REDD+. The FREL/FRL in this submission is an updated version of the previous FREL (1st FREL Indonesia in 2016) which highlighted an improved data, methodology and calculation including an improvement plan that was stated in the previous FREL. This updated FRL, will not revise or affect the previous GHG reports including FREL as REDD+ baseline, the 2nd Biennial Update Report (BUR), the REDD+ Technical Annex, Third National Communication, as well as National GHG Inventory Report. This submission meets the COP requirements by following the guidance for technical assessment and adopting the principles of transparency, accuracy, completeness, comparability, and consistency.

Experts representing cross-ministerial agencies and organizations have been mandated to facilitate the construction process through a transparent and scientific-based participatory mechanism. A stepwise approach to the calculation of the FRL was implemented, allowing Indonesia to improve the FREL/FRL by incorporating better data, improved methodologies and, where appropriate, additional pools, noting the importance of adequate and predictable support as referred to paragraph 71 of Decision 1/CP.16.

Definitions of forest, deforestation, forest degradation and peat land used in the document have been defined and clarified to ensure data consistency. The scope of the area for the FRL calculation is the land area of Indonesia that was covered by forests in year 2006, accounted for 101.1 million ha represent approximately 53.1% of the country's land area. This includes primary, secondary forests and plantation forests, irrespective of the forest estates within the national forest area defined by Ministry of Forestry (2004). In addition, 89.3 million hectares of non-forest cover are included in the FRL Scope. Three REDD+ activities have been included in this FRL construction, namely: deforestation, forest degradation, and enhancement of forest carbon stock. Aboveground biomass (AGB), below ground biomass (BGB), and carbon soil in mangrove and peatlands have been included as carbon pools in this FRL. In addition, three significant GHG gases i.e., CO_2, CH_4 and N_2O were included in the construction of the FRL.

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1. Introduction

Indonesia, on a voluntary basis, proposed the first forest reference emission level (1st FREL) based on historical average emissions over the 1990 to 2012 period, covering the activities of reducing emissions from deforestation and forest degradation. The national 1st FREL was submitted to the UNFCCC Secretariat in November 2015, and was the subject of a technical assessment by experts in 2016 facilitated by UNFCCC Secretariat. The FREL comprised only the natural forests of the Indonesian national territory, which covered an area of 113.2 million hectares in 1990, covering up to 60 % of the national territory and 78.6 % of the total forest land of the country in 1990 (excluding plantation forests). The Indonesian FREL has been constructed for crediting period from 2013 to 2020.

Decision 12/CP.17 paragraph 12, agrees that a developing country Party should periodically update the forest reference emission level and/or forest reference level (FREL/FRL) as appropriate, considering new knowledge, new trends and any modification of scope and methodologies.

Indonesia has adopted a stepwise approach to the FREL/FRL development, following paragraph 10 of Decision 12/CP.17 for improving the national FREL. Thus, the FREL/FRL improvement is done by incorporating better data, improved methodologies and, where appropriate, additional pools, highlighting the importance of adequate and predictable support as mentioned in paragraph 71 of Decision 1/CP.16. Indonesia welcomed the opportunity to voluntarily submission of the updated FREL/FRL. The updated FREL not only covers emissions from deforestation and forest degradation, but also removals from enhancement of forest carbon stocks, hence called FRL. In this submission, Indonesia takes the opportunity to include gas and carbon pools that contribute significantly to the national GHG emissions.

Indonesia underlines that the submission of the FRL is voluntary and exclusively to obtain and receive payments for REDD+ activities, under paragraph 2 of Decisions 13/CP.19, and paragraphs 7 and 8 of Decision 14/CP.19. The updated FRL will serve as a national reference for the forestry sector in reporting GHG emissions nationally and internationally. In term of subsequent use of the FRL in whole or in of it in the pursuance of REDD+ payment undertaken by Indonesia with other Parties or organizations. Indonesia will ensure, as far as possible, to maintain the principles of TACCC and to avoid double-counting and double-payment.

Consequently, the submission does not amend, revise or adjust Indonesia's commitments or position in the National Communications (NatCom), Biennial Update Report (BUR) and the updated Nationally Determined Contributions (NDC) submitted by Indonesia in the context of the Paris Agreement. This FRL has met a number of improvements following the recommendation from the technical assessment of the 1st FREL and technical analysis of the technical annex of 2nd BUR.

2. Improvement from Previous Submission

This document builds on the 1st FREL for the REDD+ submitted in 2015 and have been technically assessed by experts facilitated by UNFCCC Secretariat in 2016. The 1st FREL document has been designed as a reference for evaluating the performance of Indonesia REDD+ implementation from 2013 to 2020. Indonesia is required to submit the updated FRL for a post-2020 REDD+ implementation reference.

Indonesia retains the similarity to the 1st FREL document and considers this as an update of the first submission, which is consistent with Decision 12/CP.17. However, this submission also considers the improvement plan in the 1st submission, the suggestions from technical assessment, and lesson learnt from REDD+ frameworks in Indonesia such as the Indonesian-Norwegian Partnership and the East Kalimantan Forest Carbon Partnership Facility (FCPF) Carbon Fund.

The reference period of the FRL has been updated and shortened, from 22 years (1990 – 2012) to 14 years (2006 to 2020). Thus, the FRL will serve as a benchmark for assessing the emission reductions from the post-2020 period, i.e., 2021 – 2030.

We added several activity data for emission calculation. In the 1st submission, activity data covered only the National Forest Monitoring System (NFMS) land cover maps and peatland distribution map. In addition, burned scar maps generated from the NFMS, are used to estimate emissions from peat fires and biomass burning.

Emission factors were significantly improved in the 2nd submission. In the 1st submission, the emission factors for estimating emissions from deforestation and forest degradation only covered the AGB for forest classes. In the 2nd submission, more comprehensive emission factors have been included, covering additional carbon pools and gases. AGB, BGB, DOM, and SOC (for peat decomposition, mangrove conversion, and peat fires) pools were considered. The N_2O and CH_4 gases were also included in the calculation of peat fire and biomass burning emissions, in addition to CO_2. The carbon stock of the non-forest classes was also considered for estimating the net emission from deforestation.

The scope of the present FRL document covers an area of 101.1 million hectares of forests in 2006, and 89.3 million hectares of non-forests. The forest area equal to 53.1% of the total Indonesia land area. Overall improvement is presented in the following Table 1.

Table 1. Comparison of the Indonesia 1st FREL and the FRL

	1st FREL	**FRL**
Reference period	1990-2012	2006-2020

Activities covered	Deforestation and forest degradation	Deforestation, forest degradation, and enhancement of forest carbon stock
Scope of Areas	113.2 million ha of natural forests in 1990	101.1 million ha of forests in 2006 and 89.3 million ha of non-forests
Activity data	Land cover maps from NFMS; Ministry of Agriculture (MoA) peatland distribution map	Land cover maps from NFMS; MoA peatland distribution map; and burned areas from the NFMS
Emission factors	National Forest Inventory (NFI) 1990-2013 with complementary research data for mangrove forests[b] 2014 IPCC Guidelines on Wetland Supplement	NFI 1990-2013. NFI 2014 – 2019 in particular for mangrove forests. 2014 IPCC Guidelines on Wetland Supplement Various research on c-stock in non-forest classes, peat fire emissions, mangrove conversion and peat decomposition.
Gas	CO_2	CO_2, N_2O, CH_4
Pools	AGB and SOC with an emphasis on peat decomposition	AGB, BGB, and SOC with an emphasis on peat decomposition, mangrove conversion, and peat fires. In addition, AGB, dead wood and litter were also accounted in biomass burning

3. Definitions

3.1. Forest

Indonesia defines a forest as “a land area of more than 0.25 hectares with trees higher than 5 meters at maturity and a canopy cover of more than 30 percent, or trees able to reach these thresholds in situ” (MoFor, 2004). Therefore, the forest definition for this submission is aligned with the official Indonesian definition, and the FAO and IPCC definition, which is classified into seven classes by type and disturbance or level of succession, with only six classes classified as natural forests (*see* Table 2).

However, this submission of FRL for REDD+ activities also emphasize the importance of protecting current tropical natural forests. Accordingly, this submission also considers the differentiation of forests and natural forests in the definitions of deforestation and forest degradation.

Similar to the FREL, we apply the working definition of forests and natural forests, which is slightly different from the formal definition of forest, particularly as regards the minimum area, which is 6.25 ha rather than 0.25 ha. The working definition of forest used in this submission is “a land area of more than 6.25 ha with trees higher than 5 meters at maturity and a canopy cover of more than 30 percent” (see SNI 8033:2014 on “Method for calculating forest cover change based on results of visual interpretation of optical satellite remote sensing image”, and SNI 7645:2010 on “Land Cover Classification”).

Table 2. Forest cover classes used in the FRL

LC Code	Land-cover class	Abbreviation	Category	IPCC
2001	Primary dryland forest	PF	Natural forest	Forest
2002	Secondary dryland forest	SF	Natural forest	Forest
2004.	Primary mangrove forest	PMF	Natural forest	Forest
20041	Secondary mangrove	SMF	Natural forest	Forest
2005	Primary swamp forest	PSF	Natural forest	Forest
20051	Secondary swamp forest	SSF	Natural forest	Forest
2006	Plantation forest	TP	Plantation forest	Forest

3.2. Non-Forest Categories

Non-forest categories are land cover classes other than forest, including cropland, agricultural land, grassland, shrub, settlement, wetland and other built-up areas (Table 3). The generation of non-forest maps is part of the NFMS, which have a similar method to forest cover maps.

Table 3. Non-forest cover classes used for construction of the FRL

LC Code	Land-cover class	Abbreviation	Category	IPCC
2010	Estate crop	EP	Non-forest	Crop land
20091	Pure dry agriculture	AUA	Non-forest	Crop land
20092	Mixed dry agriculture	MxUA	Non-forest	Crop land

LC Code	Land-cover class	Abbreviation	Category	IPCC
2007	Dry shrub	Sr	Non-forest	Grassland
20071	Wet shrub	SSr	Non-forest	Grassland
3000	Savanna and Grasses	Sv	Non-forest	Grassland
20093	Paddy Field	Rc	Non-forest	Crop land
50011	Open swamp	Sw	Non-forest	Wetland
20094	Fishpond/aquaculture	Po	Non-forest	Wetland
20122	Transmigration areas	Tr	Non-forest	Settlement
2012	Settlement areas	Se	Non-forest	Settlement
20121	Port and harbour	Ai	Non-forest	Other land
20094	Mining areas	Mn	Non-forest	Other land
2014	Bare ground	Br	Non-forest	Other land
5001	Open water	WB	Non-forest	Wetland

3.3. Peatland

Peatland is defined as an area with an accumulation of decomposed organic matter, saturated with water containing at least 12% organic material content and a cumulative layer of at least 50 cm in depth (Agus *et al.*, 2016). The definition follows the commonly used definition of global peat soil of the United States Department of Agriculture (USDA) Soil Taxonomy. We used the updated peatland distribution map used based on medium and high-resolution imageries, further soil survey data and 1:50.000 map scale (Anda et al., 2021).

3.4. Deforestation

Deforestation is defined as converting natural forest cover to non-natural forest cover categories. It implies that timber harvesting in plantation forests will not be considered as deforestation. Conversely, the conversion of natural forests into plantation forests is considered as deforestation. The importance of protecting natural forests within the framework of REDD+ programme, strongly justifies Indonesia's decision to define deforestation, which is in line with Decision 1/CP.16 (Appendix 1, paragraph 2I).

This submission also considers the deforestation that occurred in the previously deforested area that had been reforested. Deforestation in this respect accounts only for what has been lost (conversion of natural forests) and does not consider forest regrowth or gain. However, in calculating the emission factor, carbon stock of post-conversion land cover classes shall be counted. Forest regrowth or reforestation is considered to be the enhancement of forest carbon stock activity, which is part of this submission.

3.5. Forest Degradation

According to The Minister of Forestry Decree No. 30/2009, forest degradation is a deterioration in the amount of forest cover and carbon stock over a certain period of time due to human activities. In this document, forest degradation is defined as changes of primary forest classes to the secondary forest classes.

The second level of forest degradation (i.e., occurs within the same forest cover class, such as primary forest or secondary forest) is excluded in this submission due to limited data and methodologies to produce accurate area estimates. Hence, the current FRL submission only considers emissions from natural forest degradation, which is consistent with the previous submission.

3.6. Enhancement of Forest Carbon Stocks

Enhancement of forest carbon stock (EFCS) is defined as the increase of carbon stock due to the changes of non-forest into forest categories (forest gain). The non-forest categories include agriculture, estate crop, grassland, shrub, settlement, and other areas. The forest categories used for assessing the EFCS include primary forests, secondary forests and plantation forests. Primary forests are included in the estimation of activity data, they are considered as secondary forests for estimating removal because the change of non-forest classes into the primary forest is doubtful. Conversion from secondary forest categories into primary forest categories is excluded from the calculation because the classification approach for the secondary forest is not suitable.

3.7. Peatland Decomposition

Primary peat swamp forests that are deforested or degraded are normally drained due to canal development for improved access. Once the peat swamp forest is drained, the mean water level decreases and creates an aerobic environment where organic soil decomposition will continue to occur if the peatlands remain drained and unforested. Consequently, deforestation and forest degradation in peatlands result in greenhouse gas emissions from peat decomposition.

In this submission, emissions from peat decomposition are accounted for in the area that has experienced deforestation, forest degradation and forest gain during the monitoring period. Therefore, emissions inherited from peat decomposition from the previous monitoring period will not be considered.

3.8. Fires

Over the past four decades, fires have frequently occurred in drained peatlands and peat swamp forests. Drained peatlands pose a significant threat during the dry season, when water levels decline significantly, leading to drought and a fire-prone environment. Peat fires consume not only dead organic matter and biomass, but also organic soils in peatlands. Emissions from peat fires are estimated based on the size of burned peatlands that are directly associated with current deforestation and forest degradation. Emissions from burned organic soils, biomass and dead organic materials are considered in this calculation.

Fires occur not only in peatland, but also in non-peatland or mineral soil areas. Fires in non-peatland areas use mostly biomass and dead organic matter. CO_2 emissions from fires other than non-peatland fires are not calculated separately because they are included in the estimates of emissions from changes in forest cover change. However, gases other than CO_2 (CH_4 and N_2O) are added to the calculation.

3.9. Mangrove Conversion

Several major drivers of mangrove deforestation which result in GHG emissions include conversion to aquaculture, agriculture, and plantations. Pristine mangrove soils provide essential nutrients and living conditions for shrimp growth. Development of the shrimp or fishponds typically involves the excavation and drainage of inundated mangrove soil, leading to emissions from the organic oxidation of the soil. Similarly, wetland drainage is necessary for cultivated areas, resulting in soil emissions due to wetland drainage. Inherited emissions from mangrove soils from previous monitoring period was not included in this calculation.

3.10. Forest Reference Level

This updated version of the 2016 FREL is aligned with Decision 12/CP.17 whereby the FREL/RL is updated periodically as appropriate, taking into account new knowledge, new trends and changes in scope and methodologies. FRL scopes cover not only emissions but also removals. The FRL serves as a benchmark for measuring performance in implementing REDD+ activities, including avoiding deforestation, forest degradation, and enhancement of forest carbon stocks, expressed in tonnes of carbon dioxide equivalent per year.

This FRL was developed based on historical emissions and removals over the reference period. The reference period used in this FRL is 2006 to 2020 (14 years). The period was shorter that the period used in the 1st FREL (22 years). The use of shorter reference period is motivated by the technical requirement from Green Climate Fund (GCF, 2017). Based on the term of reference for pilot project of Result Based Payment (RBP), it recommends 10-15 years as an ideal reference period. If it is more than 20 years or less than 5 years will be considered as failed or not accepted as reference period. In the case reference period is either between 5-10 years or 15-20 years will be accepted with a lower score, which is not an ideal period. The FRL is projected for the next ten years to compare actual emissions over the projection period, i.e., from 2021 to 2030.

Net emissions reported in this submission were derived from the emissions from deforestation, forest degradation, and increased carbon stocks. The carbon pools considered for emissions and removals were AGB, BGB, and soil. However, only peat and mangrove soil carbon were considered in estimating emissions from peat decomposition, peat fires and mangrove conversion.

4. Area, Activities and Pools Covered

4.1. Area Covered

The FRL calculation covers the terrestrial areas of Indonesia, accounting for 101.1 million hectares of forest and all non-forest categories that were cleared prior to 2006 amounted to 89.3 million hectares (Figure 1). The forest categories include natural forests and forest plantation.

The area covered for emission accounting from deforestation includes areas that in 2006, were covered by natural forests, including both in peatlands (8.0 million hectares) and mineral soils (88.8 million hectares). The area covered by primary forests in 2006 (48.4 million hectares) has been included in the calculation of forest degradation emissions. The area covered for counting EFCS removal includes all non-forest categories in 2006. The area for counting emissions from peat decomposition, peat fires and mangrove conversion, shared the same distribution as for counting of emissions from deforestation and forest degradation.

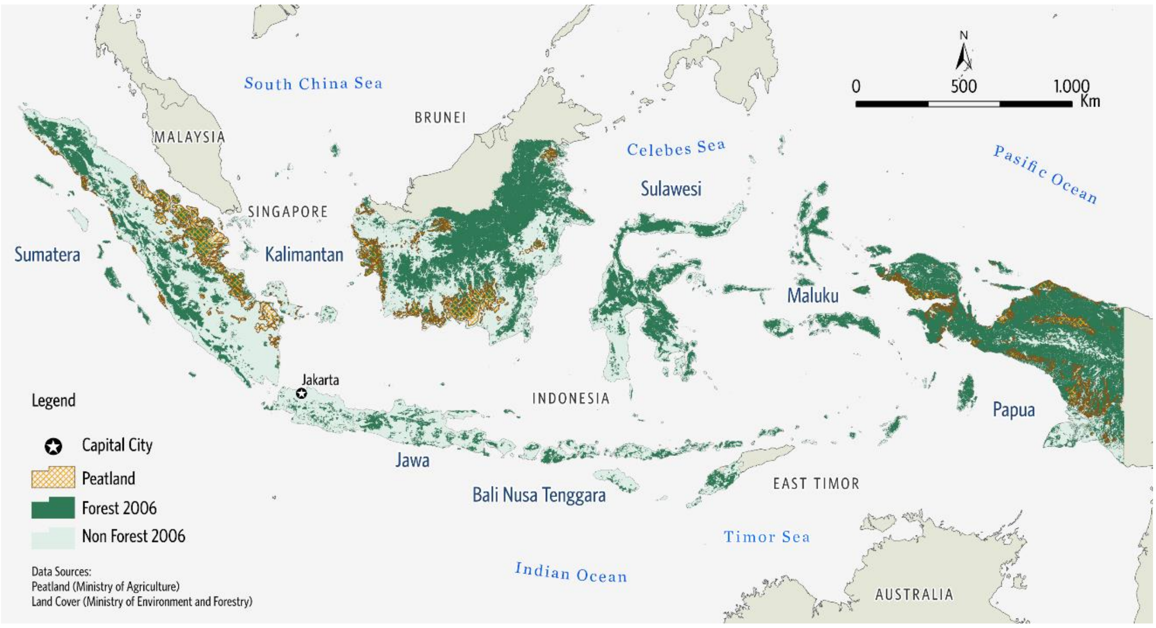

Figure 1. Scope of the area for the FREL calculation is forest classes in 2006 (101.1 million ha) and non forest classes (89.3 million ha)

4.2. Activities Covered

The REDD+ activities included in the FRL are (1) reducing deforestation, (2) reducing forest degradation, and (3) enhancement of forest carbon stocks. The latter was additional to the 1st FREL.

4.3. Pools and Gases

In this FRL, GHG emissions and removals were estimated from five carbon pools namely AGB, BGB, litter, dead wood and soil organic carbon (SOC). Litter and dead wood were included only for non-CO_2 emission estimates from fires. The emissions from SOC was estimated only from peatland and mangrove. Changes in SOC stock in mineral due to deforestation and EFCS were excluded in this report because the existing data on SOC is insufficient to generate emission factors from forest and land cover changes in Indonesia. In addition, SOC in mineral soil is also still not estimated in the national GHG Inventory reports.

Carbon dioxide was the only GHG reported in the 1st FREL, while CH_4 and N_2O gases were added in the current FRL submission. Carbon dioxide emissions were quantified from biomass and soil carbon pools including- emissions arising from deforestation, forest degradation and EFCS. In addition, CH_4 and N_2O emissions were calculated from peat fires.

5. Data, Methodology and Procedures

5.1. Data

Activity data and emission factor are keys for estimating GHG emissions. Therefore, data selection for FRL development should be based on the principles of transparency, accuracy, completeness, comparability and consistency (TACCC). It is recommended to use the best available data with known uncertainty, where future improvements are acknowledged. In addition, the data are generated based on scientifically approved methods or as part of the national system managed by a credible data custodian under the Government of Indonesia. Therefore, this ensures the data consistency, transparency, and continuity for future independent review, annual emissions measurement and emission reductions calculation from REDD+ implementation. In addition, the data sets used for this submission are consistent with other national reports for Global Forest Resource Assessment (GFRA), National Communication, National GHG Inventory, BUR and NDC.

5.1.1. Land cover data

Land cover maps that provide activity data for this submission were produced by the Ministry of Environment and Forestry (MoEF). The land cover data is part of the NFMS accessible via the NFMS website : https://nfms.menlhk.go.id/peta as online interactive and links to website of map server (http://dbgis.menlhk.go.id/arcgis/rest/services/Simontana for land cover of 1990-2018 period; https://dbgis.menlhk.go.id/arcgis/rest/services/KLHK/Penutupan_Lahan_Tahun_2019/MapServer for land cover of 2019; https://dbgis.menlhk.go.id/arcgis/rest/services/KLHK/Penutupan_Lahan_Tahun_2020/MapServer for land cover of 2020). The data also can be accessed via the One Map Web GIS, at http://tanahair.indonesia.go.id managed by Geospatial Information Agency or https://portalksp.ina-sdi.or.id/ under Coordinating Ministry for Economic Affairs. The wall-to-wall land cover maps were derived from Landsat satellite images. The land cover maps series were digitized manually for each monitoring year through visual interpretation of satellite imageries. Indonesia has generated the land cover data since 2000 based on satellite imageries dated back to 1990s (see Annex 1).

Furthermore, this FRL report used the land cover maps to generate the activity data on deforestation, forest degradation and enhancement of forest carbon stock. Activity data on deforestation was produced using the selection of the natural forest and non-natural forest categories of the initial year and the last year of the reference period, respectively. The data was used to develop the transition tables which quantified the extent of deforestation and types of non-natural forest categories after the deforestation. Similarly, forest degradation data was produced using the initial year of the primary forests and the secondary forests of the previous year of a specific reference period. The data also served to develop the forest degradation transition tables. Lastly, to generate activity data for the enhancement of forest carbon stock, we selected the non-forest categories of the initial year that changed into forest categories in the last year, particularly the secondary forest category and forest plantation.

5.1.2. National peat land data

The peatland spatial data used in this FRL was provided by the MoA, developed based on several related maps, field surveys, and accompanied ground check verification. The newly updated peatland distribution map used in this document is the revised version of the map used in the 1st FREL, which was updated in 2019 based on medium and high-resolution imageries, and additional soil survey data (Anda et al, 2021). The revised peatland map has a higher resolution (1:50,000 map scale) than the previous map version (1:250,000 map scale). More detailed method of peatland mapping is presented in Annex 2.

5.1.3. Burnt areas

Fires in peatlands have become a significant source of emissions. Although most of the fires in 2015 were from mineral soils (four times larger than fires in peatlands), the emissions originated from fires in peatlands were six times larger than emissions from fires in mineral soils (MoEF, 2016c). Deforested and drained peat swamp forests coupled with prolonged dry seasons create an environment susceptible to fires. Once the source of ignition starts, fires in drained peatlands in prolonged dry seasons will quickly spread and consume the biomass and organic matters, including organic soils, and emit massive amounts of GHG and carbon monoxide.

MoEF generated burnt areas map based on visual interpretation of medium spatial resolution of satellite imageries (KLHK, 2021). The maps were produced from 2000 to 2020 by Forest Resource Inventory and Monitoring Directorate and validated using ground truthing data by Directorate of Forest and Land Fire Control of the MoEF. The annual burnt areas on maps were overlaid with peatland maps and annual deforestation and degradation maps to generate activity data of fires. A more detailed method of burnt area mapping is presented in Annex 3.

5.1.4. Forest biomass stocks

The emission factors for deforestation, forest degradation, and enhancement of forest carbon stocks, are generated from Tier-2 data. The primary data source used to derive emission factors was the National Forest Inventory (NFI), a national program initiated by the Ministry of Forestry in 1989 and supported by the Food and Agriculture Organisation of the United Nations (FAO) and the World Bank through the NFI project.

Only PSPs data were used for calculation (Tract No. 5) for FREL. Moreover, only those that fall into natural forest classes were incorporated. These selected PSPs were dominantly located in dryland and swamp forests. Meanwhile, the NFI located in mangrove forest were insufficient to represent the estimation of the mean carbon stock. Therefore, the analysis included the temporary sample plot (TSP) data for the mangrove forest, which was collected using the point sampling method, based on basal area factor 4 (BAF 4). We estimate the AGB based on the calculated basal area of each plot. For this purpose, we developed the relationship between the basal area and the AGB.

The 1st FREL used tree allometric equations from Chave *et al.* (2005) for all forest types, although revised equations were available (Chave *et al.*, 2014). The old equations are more straightforward than the revised equation because they use additional variables related to environmental stress factor (E) that depends on the geographic location. Therefore, using locally developed equations will provide a more accurate and unbiased estimation, than global equations. The AGB of individual trees in the plots were estimated using an tree allometric model developed for Indonesia forests (Manuri *et al.*, 2017; Manuri *et al.*, 2014), namely DG2 which used diameter at breast height (D), wood density or specific gravity (G) of the species and bioregion (R) as the key parameters. The accuracy assessment between DG1 (without R parameter) and DG2 (with R parameter) showed indecisive values, for example DG2 has lower in MRE and MARE assessment, while DG1 has lower RMSE value. The selection of these two models is trivial. The author's conclusion was based on additional considerations related to the simplicity of the equation. In addition, the paper also suggested that the bioregion factor (R) is one of the most influential additional variables in explaining the variations of AGB, apart from the traditional variables (tree diameter, tree height and wood density). Moreover, region differentiation is also relevant to the NFI data used for estimating the emission factors stratified based on islands. For mangrove forest, we used allometric equation for mangrove tree species from Chave *et al.* (2005), because it is more accurate than other local mangrove allometric equations (Annex 4).

The G values were taken from the database of the MoEF through the Forest Research and Development Agency/FORDA (Krisnawati *et al*., 2012). The database is a compendium of G data for Indonesian tree species compiled from various sources (e.g., Hanum and Maesen, 1997; Oey, 1951; Lemmens and Wulijarni-Soetjipto, 1992; Lemmens *et al*., 1995; Soerinegara and Lemmens, 1994; Sosef *et al*., 1995; Suzuki, 1999; Verheij and Coronel, 1992). The database provides information on G by species, genus, and family.

The total AGB for each plot (per hectare) was then quantified by summing dry weight of AGB estimates for all trees in the plots (expressed in tonnes of dry matter (t.d.m)) as shown in Equation 1.

$$AGBp_j = \frac{\sum_{i=1}^{n} AGBt_i}{A} \qquad \text{(Equation 1)}$$

where $AGBp_j$ = Aboveground biomass (AGB) of plot - j expressed in t.d.m ha^{-1}, $AGBt_i$ = AGB of measured tree - i (t.d.m), A = plot area (ha), i = tree-i in the plot (1,2,3…n).

The total AGB per hectare for each forest type for the main islands was derived by averaging the AGB of the total plots (Equation 2).

$$\overline{AGB_k} = \frac{\sum_{j=1}^{n} AGBp_j}{n} \qquad \text{(Equation 2)}$$

where $\overline{AGB_k}$ = Mean AGB of plot for forest type - k expressed as (t.d.m ha^{-1}), $AGBp_j$ = AGB of plot - j expressed as (t.d.m ha^{-1}), A = plot area (ha), n = number of plots.

Table 4 provides a summary of AGB estimates for six forest types (primary dryland, secondary dryland, primary swamp, secondary swamp, primary mangrove, and secondary mangrove) in several main islands of Indonesia from NFI. Data were used as the basis for determining the emission factors.

Table 4. The estimates of AGB stocks from NFI in each forest type in Indonesia

Forest type	Main island	N of plot	Mean AGB (t.d.m ha^{-1})	Std Dev (t.d.m ha^{-1})	95% Confidence Interval (t.d.m ha^{-1})		Uncertainty (%)*
Primary Dryland Forest	Bali Nusa Tenggara	99	278.50	116.29	255.30	301.69	8.3
	Java	9	345.46	154.05	227.04	463.88	34.3
	Kalimantan	210	323.63	145.58	303.83	343.44	6.1
	Maluku	17	236.20	78.36	195.91	276.49	17.1
	Papua	180	266.70	122.35	248.70	284.69	6.7
	Sulawesi	243	246.55	115.96	231.90	261.21	5.9
	Sumatra	176	338.35	134.98	318.27	358.43	5.9
	Indonesia (Average)	934	289.21	132.82	280.69	297.74	2.9
Secondary Dryland Forest	Bali Nusa Tenggara	123	133.61	78.58	119.58	147.63	10.5
	Java	86	202.04	122.92	175.69	228.39	13.0
	Kalimantan	607	214.69	110.34	205.89	223.48	4.1
	Maluku	104	162.59	85.91	145.88	179.30	10.3
	Papua	126	216.48	123.34	194.73	238.22	10.0
	Sulawesi	234	159.99	83.48	149.24	170.74	6.7
	Sumatra	351	213.28	116.20	201.08	225.48	5.7
	Indonesia (Average)	1631	196.57	109.93	191.23	201.91	2.7
Primary Swamp Forest	Bali Nusa Tenggara	n.a	n.a	n.a	n.a	n.a	n.a
	Java	n.a	n.a	n.a	n.a	n.a	n.a
	Kalimantan	8	249.92	67.68	193.34	306.50	22.6
	Maluku	n.a	n.a	n.a	n.a	n.a	n.a
	Papua	73	195.37	119.12	167.58	223.16	14.2
	Sulawesi	n.d	n.d	n.d	n.d	n.d	n.d
	Sumatra	15	311.75	139.24	234.65	388.86	24.7
	Indonesia (Average)	96	218.10	125.76	192.62	243.58	11.7
Secondary Swamp Forest	Bali Nusa Tenggara	n.a	n.a	n.a	n.a	n.a	n.a
	Java	n.a	n.a	n.a	n.a	n.a	n.a
	Kalimantan	179	187.05	98.01	172.60	201.51	7.7
	Maluku	n.a	n.a	n.a	n.a	n.a	n.a
	Papua	36	121.29	82.81	93.27	149.31	23.1
	Sulawesi	1	139.48				
	Sumatra	158	179.55	91.85	165.12	193.98	8.0
	Indonesia (Average)	374	177.43	95.57	167.71	187.14	5.5
Primary Mangrove Forest	Bali Nusa Tenggara	2	174.42	69.17	76.59	272.24	56.1
	Java	2	89.15	123.14	-85.00	263.30	195.4
	Kalimantan	n.d	n.d	n.d	n.d	n.d	n.d
	Maluku	3	132.42	70.27	51.28	213.55	61.3
	Papua	8	226.70	118.75	142.73	310.67	37.0
	Sulawesi	n.d	n.d	n.d	n.d	n.d	n.d
	Sumatra	15	202.48	60.59	171.19	233.76	15.5
	Indonesia (Average)	30	192.05	62.58	169.19	214.90	11.9
Secondary Mangrove Forest	Bali Nusa Tenggara	2	178.42	59.88	93.74	263.10	47.5
	Java	3	98.31	123.80	-44.64	241.25	145.4
	Kalimantan	19	155.74	89.73	114.57	196.91	26.4
	Maluku	2	216.99	86.88	94.13	339.85	56.6
	Papua	2	135.52	124.74	-40.90	311.93	130.2
	Sulawesi	4	124.74	63.41	61.33	188.16	50.8
	Sumatra	9	106.48	64.47	63.50	149.46	40.4
	Indonesia (Average)	41	141.96	68.76	120.49	163.44	15.1

Notes: *) does not include uncertainty of allometric equation

In addition, a compilation of relevant existing studies was undertaken to improve the accuracy and address gaps in existing emission factors or carbon stocks. The distribution of NFI measurement plots in mangroves forests is still limited. Yet, there are carbon stocks measurement studies from mangrove forests in Indonesia (Komiyama *et al*., 1988; Kusmana *et al*., 1992; Alongi *et al*., 2008; Mudiyarso *et al*., 2015; Aslan *et al*., 2016; Kusumaningtyas *et al*., 2019; Nordhaus *et al*., 2019; Sidik *et al*., 2019; Cameron *et al*., 2019; Arifanti *et al*., 2019; Analudin *et al*., 2020; Asadi & Pambudi., 2020; Slamet *et al*., 2020; Sasmito *et al*., 2020). The AGB mean and SE from NFI data were combined across the studies to derive numbers of AGB for the mangrove forest. The actual value of each primary study remained unknown, but it was assumed to vary from one study area to another. The random-effects models with the restricted maximum-likelihood (REML) estimator and the Knapp and Hartung adjustment (Borenstein *et al*., 2011) were used to derive the mean and confident interval with the "metafor" package of R version 3.6.3 (R Core Team, 2020) (Figure Annex 4.4, Table Annex 4.5).

All inventory plots that provide only aboveground tree components (D≥5cm); sapling (AGB for trees with DBH < 5 cm; height > 1.5 m) and understorey vegetation (including seedlings, shrubs, vines, herbaceous plants, etc.), which are part of AGB in forest ecosystems, were not included in the tree AGB calculation in Table 4. Other unmeasured components of non tree AGB ($AGBnt$) carbon pool was estimated using Equation 3 by considering forest ecosystem types (Verwer and van der Meer, 2010; Krisnawati *et al*., 2014) based on the proportions from previous research

$$\overline{AGBT_k} = \overline{AGB_k} + \sum_{i=1}^{n}(\overline{AGB_k} \times R_{ki}) \qquad \text{(Equation 3)}$$

where $\overline{AGBT_k}$ = Mean Total AGB of all plots for forest type - k expressed as (t.d.m ha^{-1}), $\overline{AGB_k}$ = Mean tree AGB of plot for forest type - k expressed as (t.d.m ha^{-1}), R_{ki} = Ratio AGB component - i to AGB tree (%) for forest type - k, i = 1 (sapling), 2 (understorey)

Table 5 provides the estimated ratio value of sapling, understorey biomass, and root to aboveground tree biomass for six forest types (primary dryland forest, secondary dryland forest, primary swamp forest, secondary swamp forest, primary mangrove forest, and secondary mangrove forest). The ratios were used as a basis for determining the carbon stock in each carbon pool.

Table 5. The estimated ratio value of sapling, understorey biomass, and root to aboveground tree biomass in each forest type in Indonesia

Forest types	**Ratio to AGB tree (%)**		
	Sapling	**Understorey**	**Root**
Primary dryland forest	0.2	0.5	29
Secondary dryland forest	1.1	2.7	29
Primary swamp forest,	11.4	2.4	22
Secondary swamp forest	11.1	3.8	22
Primary mangrove forest	0	0	31.1
Secondary mangrove forest	0	0	11.5

Source: (Krisnawati et al., 2014)

To estimate belowground biomass (BGB), we used below equation which use root-shoot ratio (RS) used in Krisnawati et al., 2014 (Table 5).

$$\overline{BGBT_k} = \overline{AGBT_k} \times RS \qquad \text{(Equation 4)}$$

Where $\overline{BGBT_k}$ = Mean Total BGB of all plots for forest type - k expressed as (t.d.m ha^{-1}) $\overline{AGBT_k}$ = Mean Total AGB of plot for forest type - k expressed as (t.d.m ha^{-1}), R_S = Root-to-AGB ratio.

Information on carbon fraction is needed to estimate the amount of carbon (C) in each forest type. Therefore, the carbon fraction of biomass (dry weight) was assumed to be 47% (1 tonne biomass = 0.47 tonnes C) following IPCC 2006 Guideline. C stock conversion into carbon dioxide equivalent (CO_2e) was then obtained by multiplying C stock with a factor of 3.67 (44/12) (Paciornik and Rypdal, 2006).

To estimate mean total biomass, we used Equation 5, which combines all reported carbon pools for each forest cover type.

$$\overline{TB_k} = \overline{AGBT_k} + \overline{BGBT_k} \qquad \text{(Equation 5)}$$

Where $\overline{TB_k}$= Mean Total Biomass of plot for forest type - k expressed as (t.d.m ha^{-1}), $\overline{BGBT_k}$ = Mean Total BGB of plot for forest type - k expressed as (t.d.m ha^{-1}), $\overline{AGBT_k}$ = Mean Total AGB of plot for forest type - k expressed as (t.d.m ha^{-1}).

Table 6 below is to be regarded in combination with tables Annex 4.1, 4.2 and 4.3, which explain the emission factors, and their uncertainty as elaborated further in Annex 4.

Table 6. Forest biomass stocks in each forest type in Indonesia

Forest type	Main island	AGB (t.d.m ha^{-1})		BGB (t.d.m ha^{-1})		Total Biomass (t.d.m ha^{-1})		U (%)
		Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	
Primary Dryland Forest	Bali Nusa Tenggara	280.45	11.69	81.33	3.39	361.78	12.17	6.6
	Java	347.88	51.35	100.89	17.29	448.77	54.19	23.7
	Kalimantan	325.90	10.05	94.51	2.89	420.41	10.45	4.9
	Maluku	237.85	19.01	68.98	5.88	306.83	19.90	12.7
	Papua	268.57	9.12	77.88	2.63	346.45	9.49	5.4
	Sulawesi	248.28	7.44	72.00	2.14	320.28	7.74	4.7
	Sumatra	340.72	10.17	98.81	2.93	439.53	10.59	4.7
	Indonesia (Average)	291.24	4.35	84.46	1.25	375.70	4.52	2.4
Secondary Dryland Forest	Bali Nusa Tenggara	138.73	7.09	40.23	2.11	178.96	7.40	8.1
	Java	209.78	13.26	60.84	3.97	270.61	13.84	10.0
	Kalimantan	222.91	4.48	64.64	1.32	287.55	4.67	3.2
	Maluku	168.82	8.43	48.96	2.52	217.78	8.80	7.9
	Papua	224.77	10.99	65.18	3.27	289.95	11.47	7.8
	Sulawesi	166.12	5.46	48.17	1.62	214.29	5.69	5.2
	Sumatra	221.45	6.20	64.22	1.84	285.67	6.47	4.4
	Indonesia (Average)	204.10	2.72	59.19	0.80	263.29	2.84	2.1
Primary Swamp Forest	Bali Nusa Tenggara*	248.80	12.92	54.74	3.20	303.53	13.31	8.6
	Java*	248.80	12.92	54.74	3.20	303.53	13.31	8.6
	Kalimantan	285.09	24.16	62.72	7.10	347.81	25.18	14.2

Forest type	Main island	AGB (t.d.m ha^{-1})		BGB (t.d.m ha^{-1})		Total Biomass (t.d.m ha^{-1})		U (%)
		Mean	SE	Mean	SE	Mean	SE	
	Maluku*	248.80	12.92	54.74	3.20	303.53	13.31	8.6
	Papua	222.87	14.04	49.03	3.49	271.90	14.46	10.4
	Sulawesi*	248.80	12.92	54.74	3.20	303.53	13.31	8.6
	Sumatra	355.63	36.23	78.24	9.68	433.87	37.50	16.9
	Indonesia (Average)	248.80	12.92	54.74	3.20	303.53	13.31	8.6
Secondary Swamp Forest	Bali Nusa Tenggara*	204.61	4.98	45.01	1.23	249.62	5.13	4.0
	Java*	204.61	4.98	45.01	1.23	249.62	5.13	4.0
	Kalimantan	215.71	7.38	47.46	1.83	263.17	7.60	5.7
	Maluku*	204.61	4.98	45.01	1.23	249.62	5.13	4.0
	Papua	139.88	13.90	30.77	3.55	170.65	14.35	16.5
	Sulawesi*	204.61	4.98	45.01	1.23	249.62	5.13	4.0
	Sumatra	207.06	7.36	45.55	1.83	252.61	7.58	5.9
	Indonesia (Average)	204.61	4.98	45.01	1.23	249.62	5.13	4.0
Primary Mangrove Forest	Bali Nusa Tenggara*	236.17	15.26	73.45	4.66	309.62	15.96	10.1
	Java*	236.17	15.26	73.45	4.66	309.62	15.96	10.1
	Kalimantan	247.98	14.39	77.12	4.43	325.10	15.05	9.1
	Maluku*	236.17	15.26	73.45	4.66	309.62	15.96	10.1
	Papua	240.64	28.00	74.84	8.57	315.48	29.28	18.2
	Sulawesi*	236.17	15.26	73.45	4.66	309.62	15.96	10.1
	Sumatra*	236.17	15.26	73.45	4.66	309.62	15.96	10.1
	Indonesia (Average)	236.17	15.26	73.45	4.66	309.62	15.96	10.1
Secondary Mangrove Forest	Bali Nusa Tenggara*	118.02	15.72	13.57	1.78	131.59	15.82	23.6
	Java*	118.02	15.72	13.57	1.78	131.59	15.82	23.6
	Kalimantan	155.74	19.21	17.91	2.32	173.66	19.35	21.8
	Maluku*	118.02	15.72	13.57	1.78	131.59	15.82	23.6
	Papua	150.13	12.80	17.26	1.46	167.39	12.88	15.1
	Sulawesi*	118.02	15.72	13.57	1.78	131.59	15.82	23.6
	Sumatra*	118.02	15.72	13.57	1.78	131.59	15.82	23.6
	Indonesia (Average)	118.02	15.72	13.57	1.78	131.59	15.82	23.6

* *use national average value*

5.1.5. Biomass stock for non-natural forest categories

The use of carbon stock for non-natural forest classes serves as an improvement in the 2nd FRL calculation. In the previous FREL, carbon stocks in non-natural forest areas were not incorporated in the deforestation emission factor estimation. Emission estimation from deforestation was based on potential emissions, assuming that all forest carbon stocks will be lost after deforestation (also known as 'gross emission'). It means that carbon stock is only counted as a loss by deforestation when natural forests are cleared, without considering post-conversion carbon stocks (MoEF, 2016a). While in FRL, emission factor estimation from deforestation includes post-conversion carbon stocks. Therefore, information related to carbon stocks in non forest classes is required, to estimating emissions from deforestation and removals from forest carbon stocks enhancement.

Aboveground carbon stock for non-natural forest classes in this document uses a life-time average approach, which recognizes the life cycle in a land system. In this approach, carbon stock in non-natural forest classes are determined by the average carbon stock stored in a land system during rotation time. Life-time average also considers land system dynamics including regrowth and harvesting. This method enables us to compare the different land systems with various tree growth and rotation (Hairiah & Rahayu, 2007; Watson *et al*., 2000).

The emission factor for non-natural forest classes was analyzed based on compiled data from reviewed journals and scientific reports from universities and research agencies (N=182, from 57 publications). Carbon stocks in non-forest classes were determined using a weighting score. For carbon stock estimates in the dry shrub, carbon stock analysis was combined with tree canopy cover analysis using data from Hansen (source: http://earthenginepartners.appspot.com/science-2013-global-forest) to classify dry shrub areas into two categories, old shrub and young shrub. The combination between canopy cover percentage and carbon stock was used to determine the weighting score for each dry shrub category.

Aboveground carbon stock in plantation forest, estate crop, mixed agriculture and transmigration area were also analyzed using a weighting score. The weighting score for plantation forests was calculated based on the carbon stock of various plantation species and the forest plantation area of each species. Furthermore, the weighting score for an estate crop was determined based on the carbon stock in various crop commodities and the total area of each species. Meanwhile, the weighting score for mixed agriculture and transmigration area was analyzed based on tree cover percentage from Hansen and land cover map for mixed agriculture and transmigration areas. Finally, using the root-to-shoot ratio from the IPCC 2019 Refinement (IPCC, 2019); Gautam *et al*., (2021), the belowground carbon stocks were estimated by considering the ecological zone, land cover type, and aboveground carbon stock.

Table 7. Non-natural forest biomass stock in Indonesia

Non-Natural Forest Type	**AGB (t.d.m. ha^{-1})**		**BGB (t.d.m. ha^{-1})**		**Total Biomass[1] (t.dm. ha^{-1})**		**U[2]**
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**%U**
Plantation forest	161.23	16.00	52.40	5.20	213.63	16.83	15.44
Dry shrub	128.49	15.36	30.32	3.63	158.81	15.78	19.48
Estate crop	102.35	14.67	33.26	4.77	135.61	15.43	22.30
Settlement	4.61	2.48	1.34	0.72	5.95	2.58	85.18
Bare ground	5.11	2.89	1.21	0.68	6.31	2.97	92.17
Savanna and Grasses	8.64	4.13	2.04	0.98	10.68	4.25	77.88
Open water	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet shrub	41.15	8.44	9.71	1.99	50.86	8.67	33.42
Pure dry agriculture	29.95	16.38	5.99	3.28	35.94	16.71	91.10
Mixed dry agriculture	137.52	4.89	27.50	0.98	165.03	4.99	5.93
Paddy field	21.27	8.26	5.02	1.95	26.29	8.49	63.27
Fish pond/aquaculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Port and harbour	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Transmigration areas	29.95	16.38	5.99	3.28	35.94	16.71	91.10
Mining areas	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Open swamps	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Notes: 1) does not include soil organic carbon (emission from soil pool's calculated separately), 2) does not include uncertainty of allometric equation

Table 7 provides values of AGB and BGB of non-natural forest classes, derives from compilation of previous carbon stock studies in Indonesia. The units provided in Table 7 are in tonnes dry matter of biomass, while the results compiled from previous studies are in tonnes carbon (see Annex 4). To convert from carbon to biomass, we used carbon fraction of 0.47.

5.1.6. Peat and forest fires emission factors

Land clearing by human activities has affected the extent of fire in Indonesia. Massive fires in 2015 and 2019 have resulted in significant losses of carbon and increased carbon dioxide and other trace gases into the atmosphere. With the recognition of the peat fire as a significant GHG emission in Indonesia. CO_2 and CH_4 emissions from peat fires are incorporated in this FRL. Peat fires are an important emission source in Indonesia and it is strongly recommended to report emissions by applying the highest tier possible (IPCC, 2014). Here, this report conducted a meta-analysis of primary peat fire studies in Indonesia (Table 8) to better estimate peat fire emissions using the country-level emission factor.

Table 8. Parameters to estimate peat fire emissions

Parameter	Mean (SE)	Unit	Source
Cf (combustion factor)	0.54 (0.05)	-	Krisnawati et al. 2021;
Gef CO_2 (CO_2 emission factor)	1670.13 (34.03)	g kg^{-1} CO	Stockwell *et al.*2016; Stockwell *et al.*2015; Stockwell *et al.* 2014; Christian *et al.* (2003); Huijnen *et al.*2016; Setyawaty *et al.*2017; Wooster *et al.*2018; Nara *et al.*2017
Gef CH_4 (CH_4 emission factor)	177,87 (24,36)	g kg^{-1} CO_{2eq}	Stockwell *et al.*2016; Stockwell *et al.*2015; Stockwell *et al.* 2014; Christian *et al.* (2003); Huijnen *et al.*2016; Setyawaty *et al.*2017; Wooster *et al.*2018; Nara *et al.*2017
BD (bulk density)	0.16 (0.015)	g cm^{-3}	Konecny et al. 2016; Warren *et al.* 2012, Agus *et al.* 2011; Lampela *et al.*2014; Kononen *et al.* 2015; Shimada *et al.*2001
Db (Burn depth)	31.88 (4.68)	cm	Stockwell *et al.*2016; Ballhorn *et al.*2009; Konecny *et al.* 2016; Usup *et al.*2004; Page *et al.*2002; Saharjo 2007; Simpson *et al.*2016; Saharjo and Munoz 2005

**GWP methane relatives to CO2 is 21 based on second assessment report*

According to the field study of Krisnawati *et al.* (2021), combustion factor (Cf) was obtained from average values of Cf estimated over the peat depth range (10 cm – 40 cm). The emission factors of CO_2 and CH_4 were analyzed using field and laboratory-based measurements to convert peat burned mass consumed by fire to the emitted CO_2 and CH_4 gas emissions. The mean of peat burned depth was calculated from field post-fire measurement (e.g Stockwell 2015) and remote sensing application (Ballhorn *et al*. 2009; Huijnen *et al*; Konecny *et al*. 2016) which covered wildfires and controlled burning studies (Saharjo 2007; Saharjo and Munoz 2005).

Table 9. Emission factors for non-CO_2 emissions from biomass burning

Land cover	Fuel-Biomass (t ha^{-1} DM)	Combustion Factors	G_{ef} CH_4 (g kg^{-1} DM)	Gef N_2O (g kg^{-1} DM)	GWP CH_4	GWP N_2O	L_{fire}_EF CH_4 (tCO_2)	L_{fire}_EF N_2O (tCO_2)
Primary dry land forest	352.4	0.36	6.8	0.2	21	310	18.12	7.87
Secondary dry land forest	275.0	0.55	6.8	0.2	21	310	21.60	9.38
Primary mangrove forest	249.9	0.36	6.8	0.2	21	310	12.85	5.58
Primary swamp forest	297.6	0.36	6.8	0.2	21	310	15.30	6.64
Secondary mangrove forest	132.4	0.55	6.8	0.2	21	310	10.40	4.52
Secondary swamp forest	256.3	0.55	6.8	0.2	21	310	20.13	8.74

The emission factors for estimating non-CO_2 emissions from biomass burning, were derived from 2006 IPCC guidelines, i.e., combustion factors and emission factors for each gas of dry matter burnt. While the fuel mass was generated from the AGB and DOM of each forest type (Table 9).

5.1.7. Peat emission factor

Considerable areas of Indonesia's peatlands have been converted to support plantation and agricultural development in the last decades. The deforestation and degradation of peatlands are usually accompanied by drainage to remove excess water from the inundated ecosystem. Through the creation of drainage canals on peatlands for palm oil and other agricultural estates, these activities have fundamentally changed the hydrologic peat ecosystem that is intimately tied to biogeochemical reactions, by accelerating peat decomposition and releasing carbon into the atmosphere. Consequently, GHG emissions resulting from the disturbance of peat swamp forests should be adequately quantified based on the current Indonesia monitoring system.

During the 1st FREL, Indonesia relied on the default emission factor from the IPCC Wetlands Supplement (2014). Later, there were more new empirical field studies on several land use types in Indonesia. Although the GHG emissions database of tropical peatlands has been recently updated (Prananto et al., 2020), we realized that there are still some reference-related issues, including duplicated measurements, non-peer reviewed articles and methodology discrepancies in the paper. Therefore, in order to improve the emission factor from peat decomposition, the literature-derived data are used to assess the emission factor of CO_2, N_2O and CH_4 emissions based on land cover types in Indonesia.

In this current report, this report does not include non-CO_2 emissions from drainage canals due to limited data on CH_4 and N_2O emissions at the country level. This reprt applied emission factors for peat decomposition from Novita et al.

(2021), where this study analyzed 118 sampling points) based on 32 research papers to update the emission factor of CO_2 emissions.

Following the 1st FREL , we assumed that primary forests produce zero emissions or emissions that occurred naturally as this ecosystem is not affected by human intervention or canal development. The secondary dry land forests category is assumed to be similar to secondary swamp forests. Primary and secondary peat forests differentiation is based on the site description from literature, where secondary forests have been subjected to disturbance and drainage canals are yet to return to an initial condition. There is an agreement that the rate of CO_2 emissions in tropical peatlands is controlled by the water-table depth and land use type (Carlson *et al*. 2015; Hoojier *et al*. 2012; Wakhid *et al*. 2017; Prananto et al., 2020). Based on the MoEF's land cover classification, emission factors of certain classes for peatland ecosystem are not available. Because not all land cover classes neither have sufficient data nor sufficiently researched. Thus, this report follows the 1st FREL's assumption to classify the classes that are not mentioned in Novita et al 2021 into other similar land cover classes. For peatland converted to transmigration, settlement and mining areas, the emission factors for peat decomposition are assumed to be similar to those of mixed dryland agriculture, grassland and bare land, respectively. This assumption was adopted considering the similarity of the field conditions among those land cover types. Table 10 shows the summary of updated EF for CO_2 emissions (t CO_2 ha^{-1} yr^{-1}) from various land cover types in Indonesia.

Table 10. Emission factors of peat decomposition from various land cover types

Land Cover	Mean (t CO_2 $ha^{-1}yr^{-1}$)	95% Confidence Interval (t CO_2 $ha^{-1}yr^{-1}$)		Uncertainty %
Primary dryland forest	0			
Secondary dryland forest	32.42	24.85	40	23.38
Primary mangrove forest	0			
Primary swamp forest	0			
Plantation forest	72.95	50.04	95.87	31.42
Dry shrub	45.04	26.21	63.87	41.81
Estate crop	36.63	27.6	45.65	24.62
Settlement areas	45.04	26.21	63.87	41.81
Bare ground	63.79	49.61	77.98	22.24
Savanna and Grasses	45.04	26.21	63.87	41.81
Open water	0			
Secondary mangrove forest	32.42	24.85	40	23.38
Secondary swamp forest	32.42	0	0	-100.00
Wet shrub	45.04	26.21	63.87	41.81
Pure dry agriculture	45.42	25.12	65.72	44.69
Mixed dry agriculture	54.66	30.42	78.91	44.37
Paddy field	33.71	-0.72	68.14	102.14

Land Cover	Mean ($t CO_2 ha^{-1}yr^{-1}$)	95% Confidence Interval ($t CO_2 ha^{-1}yr^{-1}$)		Uncertainty %
Fish pond/aquaculture	0			
Port and harbour	0			
Transmigration areas	54.66	30.42	78.91	44.37
Mining areas	63.79	49.61	77.98	22.24
Open swamp	0			

Source: Novita et al, 2021

5.1.8. Emission factor for mangrove conversion

The selection of emission factors for estimating emissions from mangrove conversion depends on the type of post-conversion category and soil type. Regardless of the soil types, emission estimation of all mangrove conversion to aquaculture apply the emission factor based on potential emissions of soil loss due to soil excavation. Mangrove converted to cultivated lands used the emission factor from IPCC default value (Table 11).

Table 11. Emission factors for estimating emissions from mangrove conversions

Type of Mangrove Conversion	Soil Type	EF (CO_2eq tonne ha^{-1})	SE	Source
Conversion to fishpond	Peat	90.06	22.82	Arifanti et al, 2019
Conversion to fishpond	Mineral	90.06	22.82	Arifanti et al, 2019
Conversion to cultivated land	Peat	28.97	5.75	*IPCC (2014)*
Conversion to cultivated land	Mineral	28.97	5.75	IPCC (2014)

5.2. Methodology and Procedures

The principal guideline for establishing FREL/FRL shall refer to the Annex of FCCC/CP/2013/10/Add.1, i.e., Decision 13/CP 19 (Guidelines and procedures for the technical assessment of submissions from Parties on proposed forest reference emission levels and/or forest reference levels). The methodology and procedure for determining FREL need to be carefully selected from various available methodologies (Angelsen, *et al*. 2011), taking into account the national circumstances. The general reference for measuring emissions is the IPCC Guideline (2006). Step-by-step information regarding the methodological approach used in this document is described subsequently.

5.2.1. Reference period

The updated FRL used a 14-year reference period from 2006/2007 to 2019/2020. The reference period selection considered some aspects, including land cover data availability that is transparent, accurate, complete, consistent and respresents of the general condition of the current forest transition in Indonesia. The emission calculation from deforestation, forest degradation and enhancement of forest carbon stocks was based on the land cover maps of 2006/2007 and 2019/2020.

5.2.2. Land cover change analysis for generating activity data

Land cover change analysis was carried out to identify the changes in forest and land cover categories over monitoring periods. The annual land cover change analysis involves a comparison of forest and land cover (LC) maps from two subsequent periods of monitoring, previous (T_0) and current (T_1). Both T_0 and T_1 land cover data were combined using a union tool to produce a combined land cover data (LC T_0-T_1). The outputs of this analysis were activity data on deforestation (Def), forest degradation (Deg), peat decomposition (P Def and P Deg), peat fires (B P Def), mangrove conversion (MF Def) and enhancement of forest carbon stocks (ECS) (Figure 2). Where “LC” means land cover; “T_0” is the previous year; ”T_1” is the current year; “NF” is natural forest categories, which include primary forests (“PF”) and secondary forests (“SF”); “F” means forests, which include timber plantation; “Def” is deforestation; “Deg” is forest degradation; “ECS_{NonF-F}” is enhancement carbon stock from non-forest to forests; “MF” is mangrove forest; “Aq” is aquaculture; “Ag” is agriculture; “Pl” is plantation; “U” and “Int” are union and intersect, GIS function for data overlay. P and B are peatland and burned area, respectively. Unlike MMU for land cover mapping, forest cover change (deforestation) analysis uses a minimum spatial unit of 1 ha. It means, deforestation with areas equal to or more than 1 ha will be included.

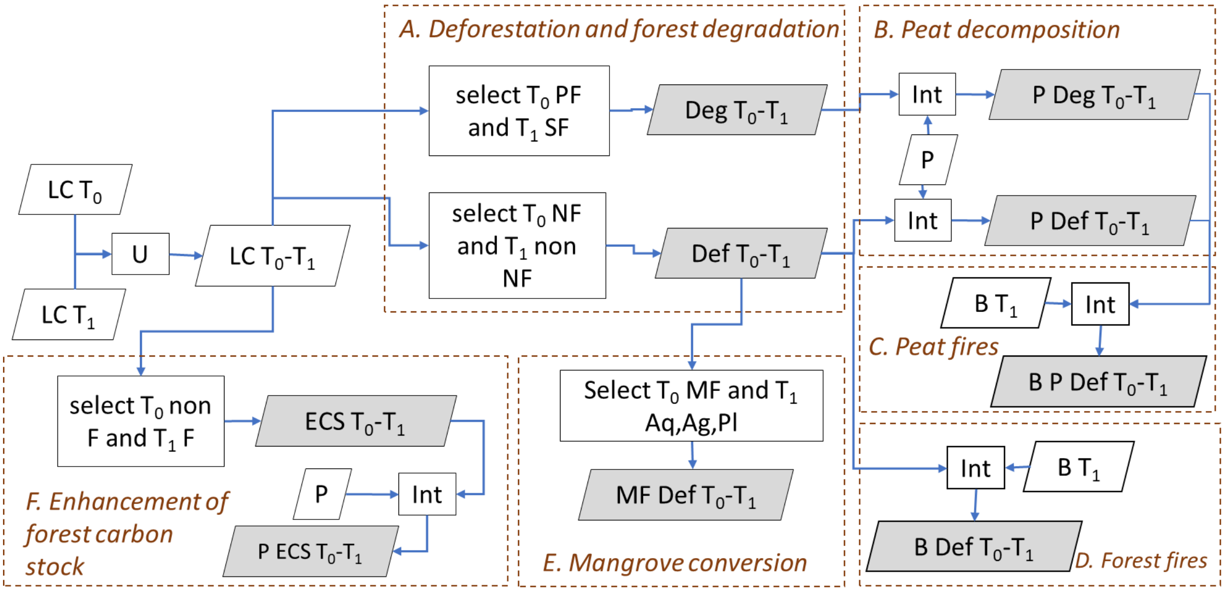

Figure 2. Flow chart of forest and land cover change analysis for generating activity data.

We generated a transition matrix, which used the LC T_0-T_1 data for each monitoring period. For forest degradation activity data, we excluded T_0 non-primary forests and T_1 non secondary forests from the transition matrix (Figure 2A). Similarly, we excluded T_0 non-forest and T_1 non-forests in the transition matrix to produce deforestation activity data.

For this submission, we used the activity data of land cover change from two points of year, i.e. initial year and end year of the reference period. We consider the current method is more straight forward than the method used in the 1st FREL, but still covers the dynamic of forest and land cover change during the reference period. Secondly, this method filters out the error due to the wrong classification of deforestation and forest gain. In the 1st FREL we had to apply additional filter to exclude the area that has been deforested during the reference period and deforested again later during the reference period. We assume that forest gain in short period is not possible. The current method is automatically excluded the error. Lastly, this method is in line with the data that are used for the uncertainty analysis of the activity data using the sample-based approach., We intersected the deforestation and forest degradation areas with peatland data (Figure 2B) to determine peat decomposition activity data. All deforestation and forest degradation areas that occurred in peatlands were considered for generating activity data of peat decomposition.

Furthermore, we intersected the deforested peatlands with burnt areas to generate burnt peatland activity data for estimating peat fire emissions (Figure 2C). All burnt deforested peatlands were included for estimating emissions from peat fires. To generate activity data for biomass burning, we intersected the deforested areas with burned areas (Figure 2D).

To generate activity data on mangrove conversion for cultivation, we further analysed the transition matrix of deforestation by excluding all non-mangrove forests of previous land cover and all non-cultivated areas of current land cover maps (Figure 2E). The cultivation areas included agriculture, aquaculture, estate crops and plantation.

Enhancement of forest carbon stocks involves the enhancement of non-forest to forest categories (ECS_{NonF-F}) (Figure 2F). the same land cover transition matrix was analysed To generate the activity data for ECS_{SF-PF}, by excluding all non-secondary natural forests of previous land cover maps and all non-primary forest categories of current land cover maps.

Land cover mapping uses Landsat satellite imageries (medium spatial resolution: 30 m) as the primary data source for visual interpretation. In addition, the use of visual interpretation methods on Landsat images is able to detect changes from forest to non-forest due to land clearing caused by human activities, such as agriculture, plantations and settlements, fires, and natural disasters. Monitoring of forest degradation (decrease in forest quality) was carried out at level one of forest degradation, i.e., the changes from primary forest to secondary forest. Level one forest degradation represents partial loss of primary forest stands. Detection of forest degradation on Landsat imagery uses the assumption of the proximity of any human influence such as land clearing, road access, settlements, land management, and forest fires within 1 km buffer. This assumption considers the topographic and physical condition of the area. Hence, detection of second-level forest degradation (e.g., changes in forest cover quality or canopy decline at secondary forest class), is not yet possible to be conducted because of the method used.

5.2.3. Emission calculation from deforestation and forest degradation

Emission from deforestation and forest degradation (E) were estimated based on the stock-difference approach, which deducting the total carbon stock in T_0 with total carbon stock in T_1. The total carbon stocks were calculated by multiplying area of deforestation or degradation in hectares with the associated carbon stocks. A conversion factor from C to CO_2, equals to 44/12, was further multiplied to derived emissions in tCO_2 equivalent (see Equation 6).

$$E_{bio} = \frac{\sum_{i=1}^{n}(A_{it0} \times C_i) - \sum_{j=1}^{m}(A_{jt1} \times C_j)}{t1 - t0} \times \left(\frac{44}{12}\right); \ \sum A_i = \sum A_j \qquad \text{(Equation 6)}$$

Where E_{bio} is CO_2 biomass emission or removal ($tCO_2\ yr^{-1}$). A_{ito} is area of land cover -i on t0 changed into land cover type-j (hectares). A_{jt1} is area of land cover - j on t1 (hectares). C_i and C_j are the carbon stock from of land cover class-i from t_0 and land cover class-j from t1, respectively ($tCO_2\ ha^{-1}$).

- Deforestation ($Edef_{bio}$) : A_i is area of land cover natural forest class - i that deforested change into land cover non natural forest class - j, A_j is area of land cover non natural forest class post deforestation.
- Forest degradation ($Edeg_{bio}$) : A_i is area of land cover primary natural forest class - i that degraded into land cover secondary natural forest class - j, A_j is area of land cover secondary natural forest class post forest degradation.

5.2.4. Removals calculation from enhancement of forest carbon stock

To estimate removals from enhancement of forest carbon stock (ECS), we used stock-difference approach, the same approach used for emission calculations. Removals from ECS are calculated using the Equation 7.

$$\mathrm{Recs}_{bio} = \frac{\sum_{i=1}^{n}(A_{it0} \times C_i) - \sum_{j=1}^{m}(A_{jt1} \times C_j)}{t1 - t0} \times \left(\frac{44}{12}\right); \sum A_i = \sum A_j \qquad \text{(Equation 7)}$$

Where Recs_{bio} is biomass removal ($tCO_2\ yr^{-1}$) from enhancement of forest carbon stock. A_i is area of land cover non natural forest class - i that change into land cover natural forest class - j, A_j is area of land cover natural forest class post planting/regrowth (hectares). C_i and C_j are the carbon stock from of land cover class-i from t_0 and land cover class-j from t1, respectively ($tCO_2\ ha^{-1}$).

We excluded the changes of secondary forest to primary forests, because the changes from secondary to primary forests is not possible, within our terminology. Based on the definition that is used in map classification, secondary forest exhibit signs of logging activities indicated by patterns and spotting of logging (appearance of roads and logged-over patches). In this spatial processing analysis, this condition may happen because the polygons that turned into primary forest occurred at the perimeter of the primary forest, which is not derived from individual polygons.

5.2.5. Emission calculation from peat decomposition

Emissions from peat decomposition are calculated folowing the Equation 8.

$$E_{pd} = \frac{\sum_{i=1}^{n}(A_{ito} \times EF_i) + \sum_{j=1}^{m}(A_{jt1} \times EF_j)}{2}; \ \sum A_i = \sum A_j \qquad \text{(Equation 8)}$$

Where E_{pd} is CO_2 emission ($tCO_2e\ yr^{-1}$) from peat decomposition in peat forest area that experiencing deforestation (Def), forest degradation (Deg) and enhancement carbon stock (Ecs). A_{ito} is area of peat land cover -*i* on t_0 changed into land cover type-*j* (hectares). A_{jt1} is area of peat land cover - *j* on t_1 (hectares). EF_i and EF_j are the emission factors from peat decomposition of land cover class-*i* from t_0 and land cover class-*j* from t_1, respectively ($tCO_2e\ ha^{-1}\ yr^{-1}$). We used the average emission factors (both EFs devided by two), assuming that the forest cover change was happening in the middle of reference period

- Deforestation ($Edef_{pd}$) : A_i is area of land cover natural forest class - i that deforested change into land cover non natural forest class - j, A_j is area of land cover non natural forest class post deforestation.
- Forest degradation ($Edeg_{pd}$) : A_i is area of land cover primary natural forest class - i that degraded into land cover secondary natural forest class - j, A_j is area of land cover secondary natural forest class post forest degradation.
- Enhancement of forest carbon stock ($Eecs_{pd}$): A_i is area of land cover non natural forest class - i that change into land cover natural forest class - j, A_j is area of land cover natural forest class post planting/regrowth.

To avoid double counting with emissions from mangrove forests converted to cultivated lands in peatland, we excluded this emission from peat decomposition calculation. Because the emissions from mangrove conversion into cultivated lands in peatlands were accounted in emissions from mangrove conversion (see sub-chapter 5.2.7).

5.2.6. Emissions calculation from fires

There are two types of emissions cased from fires, i.e., peat fires and biomass burning from deforestation and forest degradatin areas. Emissions from peat fires (E_{pf}) are calculated using Equation 7 derived from IPCC, 2014 and Equation 9 and Equation 10.

$$Epf_i = AD_{pf} \times DB_{pf} \times BD \times Cf_i \times Gef_i \times GWP_i \ \times 10^{-1} \text{ (Equation 9)}$$

Where Epf_i is the emission from peat fires for a specific gas- i in $tCO_2\ yr^{-1}$, AD_{pf} is the activity data of burned peatland in deforested areas (ha yr^{-1}) , DB_{pf} = average burned peat depth in cm, BD is bulk density of peat soil in $g.cm^{-3}$, Cf_i is combustion factor for a specific gas - i , Gef_i is emission factor for a specific gas - i of burned peat soil in $g.kg^{-1}$, i is specific gas and source category : 1 (CO_2), 2 (CH_4). GWP_i is global warning potential values for 100-year time horizon used for converting non CO_2 gases to CO_2 equivalent. For CO_2 gas, the GWP therefore equals to 1. For CH_4 and N_2O we used GWP of 21 and 310, respectively, following the IPCC Second Assessment Report (AR2).

To estimate total emissions from peat fires in deforested area ($Edef_{pf}$) we used Equation 10.

$$Edef_{pf} = \sum_{i=1}^{n} Epf_i \qquad \text{(Equation 10)}$$

where $Edef_{pf}$ is the total peat fires emissions from deforestation activity.

We include only soil organic carbon pool when calculating peat fire emissions to avoid double counting with deforestation and forest degradation emissions.

We estimated the emissions from biomass burning (E_{bb}) using Equation 11 and Equation 12, which include only non-CO_2 gases, to avoid double counting with biomass emissions from deforestation and forest degradation.

$$E_{bbi} = ADburnt_j \times DM_j \times Cf_j \times EF_i \times C_{frac} \times GWP_i \times (44/12) \qquad \text{(Equation 11)}$$

$$E_{bb} = \sum_{i=1}^{n} E_{bbi} \qquad \text{(Equation 12)}$$

Where E_{bbi} is total emission from biomass burning of a specific non-CO_2 gas-i from fires in $tCO_2\ yr^{-1}$, $ADburnt_j$ is the activity data of burned areas (ha yr^{-1}) in natural forest class-j that deforested (Def) or experiencing forest degradation (Deg), DM_j = Fuel biomass (t.d.m ha^{-1}) in natural forest class-j, Cf_i is combustion factor for a specific gas - i , EF_i is emission factor for a specific gas - i of in $g.kg^{-1}$, C_{frac} is Carbon fraction in (tC $t.d.m^{-1}$), i is specific gas and source category, i.e.: N_2O and CH_4, GWP is global warning potential values for 100-year time horizon used for converting non CO_2 gases to CO_2 equivalent.

Deforestation ($Edef_{bb}$) : $ADburnt_j$ is the activity data of burned areas (ha yr^{-1}) in natural forest class-j that deforested. Forest degradation ($Edeg_{bb}$) : $ADburnt_j$ is the activity data of burned areas (ha yr^{-1}) in natural primary forest class-j degraded into land cover secondary natural forest class.

To avoid double counting with emissions calculation from deforestation and forest degradation, we include only non-CO_2 gas for estimating emissions from burned biomass.

5.2.7. Emissions calculation from mangrove conversion

Emissions from mangrove conversion are calculated using the Equation 13.

$$Edef_m = \sum(AD_i \times EF_i) \qquad \text{(Equation 13)}$$

Where $Edef_m$ is Mangrove soil emissions from deforestation for aquaculture development and cultivated land in $tCO_2\ yr^{-1}$, AD_i is activity data of after deforestation, and EF_i is the emission factor for soil extraction in activity - i, i = 1 (aquaculture development), and 2 (cultivated land).

Conversion from mangrove forests into aquacultures involves deforestation directly and indirectly. Some fishponds may be built from previously unforested areas, such as shrubs or swamps, which were deforested in the previous monitoring period. Meanwhile, this analysis covers only the development of aquaculture that consists of mangrove forests.

5.2.8. Reference level calculation

Reference level (RL) was calculated based on the total annual emissions and removals of all reported REDD+ activities from the reference period, i.e., from historical emissions from deforestation and forest degradation and removals from ECS (see Equation 14).

$$RL = E_{def} + E_{deg} + R_{ecs} \qquad \text{(Equation 14)}$$

To calculate total emissions from deforestation (E_{def}), forest degradation (E_{deg}) and removals from enhancement of forest carbon stock (R_{ecs}) we used Equation 15, Equation 16, and Equation 17, respectively.

$$E_{def} = Edef_{bio} + Edef_{pd} + Edef_{pf} + Edef_{bb} + Edef_m \qquad \text{(Equation 15)}$$

$$E_{deg} = Edeg_{bio} + Edeg_{pd} + Edeg_{bb} \qquad \text{(Equation 16)}$$

$$R_{ecs} = Recs_{bio} + Eecs_{pd} \qquad \text{(Equation 17)}$$

5.2.9. Uncertainty calculation

Uncertainty analysis is required to quantify the combined uncertainty of emission and removal estimates using the Monte Carlo simulation. However, according to IPCC (2006) it is encouraged to use a combination of approach 2 (Monte Carlo Simulation) and approach 1 (Propagation Error) to quantify the overall uncertainty of the estimates.

We used a spreadsheet template for uncertainty analysis using Monte Carlo simulation developed by FAO[1]. The spreadsheet used a combination of approach

[1] https://www.fao.org/redd/information-resources/tools/en/

1 and approach 2 to quantify the uncertainty of each category and overall emissions. Approach 2 was used to estimate the uncertainty of each activity data and individual carbon pool's emission factor. Approach 1 was used to combine uncertainties from different carbon pools and overall uncertainties from all activities, based on error propagation. These uncertainty estimates were combined using two convenient rules for combining uncorrelated uncertainties under addition and multiplication.

Furthermore, we performed Monte Carlo Simulation using the following steps. Firstly, we conducted the accuracy assessment, to evaluate the accuracy of the land cover change maps, such as deforestation, forest degradation, and forest gain. In addition, non-change categories, stable forests and stable non-forest were assessed. Secondly, we conducted uncertainty analysis to adjust the land cover change areas based on the map accuracies. A more detail description of the method adopted from Olofsson *et al.* (2014) is provided in the Annex 1. From these steps, we generated the mean and standard error of ADs.

Thirdly, we input all means and standard errors of ADs and EFs into the Monte Carlo Simulation spreadsheet. Mean and standard error of the EFs were compiled separately from the best available data. The Probability Density Function (PDF) was defined to estimate the 2.5% and 97.5% quantiles that calculate the lower and upper uncertainties of the total emissions from a category. We assumed that all ADs and EFs have a normal distribution and used a 95% confidence level for estimating the random values of ADs and EFs. Based on the selected random values of ADs and EFs, the annual emissions of each activity were simulated with 10,000 iterations.

6. Results of the Construction of Forest Reference Level (FRL)

6.1. Activity Data of Deforestation, Forest Degradation, Enhancement of Forests Carbon Stocks, Peat Decomposition, Peat Fires and Mangrove Conversion

6.1.1. Deforestation

6.1.1.1. Activity data for biomass loss

The average deforestation in Indonesia from 2006/2007 to 2019/2020 was 599,232 hectares. Secondary drylands and secondary swamp forests were the most deforested forest type at 359,853 hectares and 175,153 hectares annually (Table 12). The land use/land cover type post conversion was dominated by estate crops, dry shrubs and mixed agriculture, which accounted for 170,065 hectares, 116,339 hectares and 108,203 hectares, respectively (Table 13).

Table 12. Annual deforestation occurred during the reference period

Forest Strata	AD Deforestation ($ha\ yr^{-1}$)	SE ($ha\ yr^{-1}$)
Primary dryland forest	29,636	8,870
Secondary dryland forest	359,853	30,908
Primary mangrove forest	3,060	2,850
Primary swamp forest	17,224	6,762
Secondary mangrove forest	14,305	6,163
Secondary swamp forest	175,153	21,564
Total	**599,232**	**39,885**

Table 13. Post-conversion land use categories after deforestation

Strata	AD Post Deforestation ($ha\ yr^{-1}$)	SE ($ha\ yr^{-1}$)
Plantation forest	60,050	12,626
Dry shrub	116,339	17,574
Estate crop	170,065	21,248
Settlement	4,300	3,379
Bare ground	24,524	8,069
Savanna and Grasses	9,047	4,901
Open water	3,741	3,152
Wet shrub	66,413	13,278
Pure dry agriculture	17,711	6,857
Mixed dry agriculture	108,203	16,949
Paddy field	3,785	3,170
Fish pond/aquaculture	5,343	3,766

Strata	AD Post Deforestation (ha yr^{-1})	SE (ha yr^{-1})
Port and harbor	59	397
Transmigration areas	335	943
Mining areas	6,901	4,280
Open swamps	2,416	2,532
Total	**599,232**	**39,885**

6.1.1.2. Activity data for peat decomposition

Activities data for the calculation of peat decomposition were determined by the importance of deforestation and forest degradation in peatlands. The average annual deforestation on peatlands was 122,254 ha annually and occurred mainly in secondary swamp forests (107,313 ha) and primary swamp forests (11,173 ha). The least significant deforestation on peatland was the deforestation of primary mangroves, with only 48 ha or 0.04% of the total deforestation on peatlands (Table 14). Further analysis revealed that most of the natural forest deforestation on peatlands has been converted to estate crops (47,438 ha), wet shrubs (33,874 ha), and plantation forests (25,546 ha) (Table 15). Mangrove conversion for cultivation in peatland, was also quantified for the activity data for peat emission calculation. Therefore, to avoid double counting, emissions from magrove conversion from cultivation areas are excluded in this calculation but included in emission calculation from mangrove conversion (6.1.1.3). During the reference period, mangroves conversion into cultivated areas in peatlands was only 11 hectares per year (Table 16).

Table 14. Activity data peat decomposition deforested area (T_0)

Forest Strata	AD peat decomposition deforested T_1 (ha yr^{-1})	SE (ha yr^{-1})
Primary dryland forest	254	371
Secondary dryland forest	3,186	1,314
Primary mangrove forest	48	162
Primary swamp forest	11,173	2,460
Secondary mangrove forest	278	388
Secondary swamp forest	107,313	7,624
Total	**122,254**	**8,137**

Table 15. Activity data peat decomposition deforested area (T_1)

Strata	AD peat decomposition deforested T_2 (ha yr^{-1})	SE (ha yr^{-1})
Plantation forest	25,546	3,720
Dry shrub	1,532	911
Estate crop	47,438	5,069
Settlement	48	161
Bare ground	6,804	1,920
Savanna and Grasses	26	118

Strata	AD peat decomposition deforested T_2 (ha yr^{-1})	SE (ha yr^{-1})
Open water	51	166
Wet shrub	33,874	4,283
Pure dry agriculture	1,775	981
Mixed dry agriculture	4,126	1,495
Paddy field	111	246
Fish pond/aquaculture	24	113
Port and harbor	3	43
Transmigration area		
Mining areas	245	365
Open swamps	649	593
Total	**122,254**	**8,137**

Table 16. Activity data on mangrove conversion to cultivated land in peat soil

Conversion type	AD Mangrove conversion (ha yr^{-1})	SE (ha yr^{-1})
Mangrove forests to cultivated areas	11	1
Total	**11**	**1**

6.1.1.3. Activity data for forest fires

The average annual burnt forest in peatlands that led to deforestation from 2006/2007 to 2019/2020 was about 41,073 hectares annually (Table 17). Forest fires have also taken place in peatlands and mineral soils, from which biomass combustion also emits gases other than CO_2 gases, such as N_2O and CH_4. The average annual area burnt, leading to deforestation over the reference period was 88,942 ha annually. Fires mainly occurred in secondary swamp forests (53,111 hectares), and secondary dryland forests (29,522 hectares) (Table 18).

Table 17. Burnt peat forests

Activity	AD peat fire (ha yr^{-1})	SE (ha yr^{-1})
Peat fire	41,073	2,734

Table 18. Activity data of forest biomass burning in deforestation areas for non-CO_2 gas emission calculation

Forest Strata	AD Non-CO_2 from fire (ha yr^{-1})	SE (ha yr^{-1})
Primary dryland forest	1,881	861
Secondary dryland forest	29,522	3,411
Primary mangrove forest	133	229
Primary swamp forest	3,817	1,226
Secondary swamp forest	478	434
Secondary swamp forest	53,111	4,575
Total	**88,942**	**5,920**

6.1.1.4. Activity data for mangrove conversion

The conversion of mangroves into mineral soils occurred over a larger area than the conversion of mangroves into peat soils. The average annual mangrove conversion rate on mineral soils was 9,017 hectares annually (Table 19). The post-conversion land use area is approximately the same value for both fishpond and cultivation areas. Annual conversion to fishponds was slightly higher (4,796 hectares), than the mangrove's conversion to cultivated land (4,222 hectares).

Table 19. Activity data on mangrove conversion

Activity	AD mangrove soil (ha yr^{-1})	SE (ha yr^{-1})
Mangrove converted to fish pond	4,796	319
Mangrove converted to cultivated land	4,222	281
Total	**9,017**	**425**

6.1.2. Forest degradation

6.1.2.1. Activity data for biomass loss

In Indonesia, the average annual forest degradation from 2006/2007 and 2019/2020 was about 208,845 hectares, which consists of 175,741 ha of primary to secondary dry forest, 26,596 of forest degradation of swamp forests and 6,509 hectares of primary to secondary mangroves (Table 20).

Table 20. Activity data of forest degradation (natural forest)

Activity	AD forest degradation: natural forest (ha yr^{-1})	SE (ha yr^{-1})
Primary dryland forest – secondary dryland forest	175,741	32,097
Primary mangrove forest – secondary mangrove forest	6,509	6,177
Primary swamp forest – secondary swamp forest	26,596	12,486
Total	**208,845**	**34,990**

6.1.2.2. Activity data for peat decomposition

Average annual forest degradation on peatlands amounted to 11.332 ha yr^{-1}. Aligned peat decomposition over deforestation, the most degraded forest was swamp forest (9,931 ha yr^{-1}) and the second larget was dry land forest (1,052 ha yr^{-1}), as seen in the Table 21

Table 21. Activity data of forest degradation in peatlands

Activity	AD forest degradation: peat (ha yr^{-1})	SE (ha yr^{-1})
Primary dryland forest – secondary dryland forest	1,052	578
Primary mangrove forest – secondary mangrove forest	349	333
Primary swamp forest – secondary swamp forest	9,931	1,777
Total	**11,332**	**1,899**

6.1.2.3. Activity data for forest fires

In forest degradation areas, only 497 hectares were burnt per year. The largest forest fire was linked to the degradation of primary dryland forest and primary swamp forest (Table 22).

Table 22. Activity data of forest biomass burning in forest degradation areas for non-CO_2 gas emission calculation

Activity	AD forest degradation (ha yr-1)	SE (ha/yr)
Primary dryland forest – secondary dryland forest	348	70
Primary mangrove forest – secondary mangrove forest	12	13
Primary swamp forest – secondary swamp forest	137	44
Total	**497**	**83**

6.1.3. Enhancement of forest carbon stock

6.1.3.1. Activity data for biomass removal

Efforts under the EFCS over the reference period occur primarilly in dry shrubs (50%), wet shrubs (16%), and mixed dryland agriculture (11%) areas. Meanwhile, the lowest percentage of forest gains or EFCS occurs in ports and harbours (0.002%) from the total EFCS activities area, which could be part of a land cover classification error. The average annual forest gain area was 75,091 ha yr^{-1} (Table 23 and Table 24).

Table 23. Activity data initial EFCS (T_0)

Land cover type	AD initial EFCS (T_0) (ha yr^{-1})	SE (ha yr^{-1})
Dry shrub	37,736	10,974
Estate crop	1,832	2,418
Settlement	157	708
Bare ground	4,997	3,993
Savanna and Grasses	4,562	3,816
Open water	568	1,346
Wet shrub	12,289	6,263
Pure dry agriculture	2,417	2,777
Mixed dry agriculture	8,291	5,144
Paddy field	1,001	1,787
Fish pond/aquaculture	374	1,092
Port and harbor	1	63
Transmigration areas	64	453
Mining areas	132	649
Open swamps	671	1,463
Total	**75,091**	**15,481**

The table below shows that post-conversion forest cover after forest gain is dominated by secondary dryland forest (48%), plantation forest (32%) and secondary swamp forest (13%). The smallest area of forest gain activities was mainly swamp forests, respresenting only 135 ha or 0.2% of the total forest gain over the reference period.

Table 24. Activity data EFCS – forest (T_1)

Type of Enhance of Forest Carbon Stock	AD – Forest (T_1) (ha yr^{-1})	SE (ha yr^{-1})
Primary dryland forest	3,136	3,164
Secondary dryland forest	35,982	10,716
Primary mangrove forest	478	1,235
Primary swamp forest	135	656
Secondary mangrove forest	2,010	2,533
Secondary swamp forest	9,453	5,493
Plantation forest	23,898	8,733
Total	**75,091**	**15,481**

6.1.3.2. Activity data for peat decomposition

EFCS activities also took place in peat soil, as presented in the table below, with an average annual rate of 10,258 ha yr^{-1} during the reference period. EFCS activities on peat soil mostly occurred in wet shrub (62%), bare ground (24%), and dry shrub (5%). EFCS in other land use type were relatively small, varying from 0.3 ha to 330 ha (Table 25).

Table 25. Initial land cover class and the activity data of EFCS in peatland (T_0)

Land cover type	AD Peat (T_0) (ha yr^{-1})	SE (ha yr^{-1})
Dry shrub	512	472
Estate crop	330	379
Settlement	3	37
Bare ground	2,428	1,029
Savanna and Grasses	96	205
Open water	43	137
Wet shrub	6,346	1,663
Pure dry agriculture	28	111
Mixed dry agriculture	66	170
Paddy field	1	17
Fish pond/aquaculture	1	17
Port and harbor		
Transmigration areas	0	5
Mining areas	4	43
Open swamps	400	418
Total	**10,258**	**2,115**

EFCS activities on peatlands showed that most of the EFCS area was afforested/reforested into plantation forest (7,595 ha yr^{-1}), and secondary swamp forests (2,308 ha yr^{-1}). The other forest strata were relatively small, ranging in size from 6 ha to 170 ha yr^{-1}, or less than 2% of the total reforested areas (Table 26).

Table 26. Post-conversion forest types and the activity data on EFCS in peatland (T_1)

Type of Enhancement of Forest Carbon Stock	AD peat - forest (T_1) (ha yr^{-1})	SE (ha yr^{-1})
Primary dryland forest	6	49
Secondary dryland forest	170	272
Primary mangrove forest	10	65
Primary swamp forest	56	156
Secondary mangrove forest	114	223
Secondary swamp forest	2,308	1,003
Plantation forest	7,595	1,820
Total	**10,258**	**2,115**

6.2. Emissions from Deforestation, Forest Degradation, and Peat Decomposition

6.2.1. Emissions from deforestation

6.2.1.1. Biomass emissions

The average annual emissions of AGB and BGB due to deforestation from 2006 to 2020 were approximately 139.6 $MtCO_2e$ annually (Table 28). Total forest carbon loss during the reference period was 271.7 $MtCO_2e$ annually (Table 27). The highest biomass emissions from deforestation were predominantly from secondary dryland forests and secondary swamp forests, with an initial carbon stock of 163.3 $MtCO_2e$ and 75.3 $MtCO_2e$, respectively. Total post-conversion carbon stock was 132.1 $MtCO_2e$, mostly stored in estate crops, dry shrubs, mixed agriculture, and forest plantations (Table 28).

Table 27. Forest carbon stock before deforestation (T_0)

Forest Strata	C Stock ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Primary dryland forest	19,187,858	5,747,588
Secondary dryland forest	163,277,663	14,134,355
Primary mangrove forest	1,632,688	1,523,102
Primary swamp forest	9,009,829	3,559,201
Secondary mangrove forest	3,244,118	1,450,958
Secondary swamp forest	75,348,681	9,404,591
C Stock T_1	**271,700,837**	**18,394,404**

Table 28. Post-conversion carbon stock after deforestation (T_1)

Strata	C Stock ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Plantation forest	22,107,576	4,963,879
Dry shrub	31,840,443	5,757,530
Estate crop	39,744,980	6,716,329
Settlement	44,068	39,571
Bare ground	266,741	153,107
Savanna and Grasses	166,593	111,923
Open water	-	
Wet shrub	5,821,482	1,529,701
Pure dry agriculture	1,097,032	663,643
Mixed dry agriculture	30,772,960	4,909,218
Paddy field	171,500	153,936
Fish pond/aquaculture	-	
Port and harbour	-	
Transmigration areas	20,756	58,628
Mining areas	-	
Open swamps	-	

Strata	C Stock ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
C Stock T_1	**132,054,133**	**11,394,903**
Net Emissions from Deforestation ($T_0 - T_1$)	**139,646,704**	**21,637,882**

6.2.1.2. Emissions from peat decomposition

Annual average emissions from peat decomposition in deforestation areas with peat soil were 4.8 million tCO_2. Annual emission levels in the initial and the last year of the reference period were 3.6 million tCO_2 and 6.0 tCO_2, respectively (Table 29 and Table 30). In addition, peat decomposition due to deforestation also occurred where mangroves on peatsoil were converted into cultivation, which accounted for only less than 1.0 thousand tCO_2e annually. To avoid double counting with emissions in mangrove conversion, we excluded the emission from mangrove conversion in peat soils.

Table 29. Emission peat decomposition of the initial baseline year on deforested areas (T_0)

Forest Strata	Emission Peat Decomposition Deforested T_0 ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Primary dryland forest	-	
Secondary dryland forest	103,302	44,200
Primary mangrove forest	-	
Primary swamp forest	-	
Secondary mangrove forest	9,019	12,627
Secondary swamp forest	3,479,103	468,616
Emission peat decomposition all strata T_0	**3,591,425**	**470,865**

Table 30. Emission peat decomposition of latest baseline year on deforested areas (T_1)

Strata	Emission peat decomposition deforested T_1 ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Plantation forest	1,863,600	377,625
Dry shrub	69,021	43,028
Estate crop	1,737,651	280,779
Settlement	2,165	7,278
Bare ground	434,041	124,501
Savanna and Grasses	1,158	5,320
Open water	-	
Wet shrub	1,525,679	345,179
Pure dry agriculture	80,641	47,073
Mixed dry agriculture	225,536	89,301
Paddy field	3,756	8,369
Fish pond/aquaculture	-	
Port and harbor	-	
Transmigration areas		
Mining areas	15,648	23,266

Strata	Emission peat decomposition deforested T_1 ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Open swamps	-	
Emission peat decomposition all strata T_1	**5,958,896**	**607,307**
Emission Mangrove on peat – Cultivated (Excluded)	**801**	**125**
Emissions-Peat Dec per year (T_0+T_1-Excluded)/2	**4,774,760**	**384,232**

6.2.1.3. Emissions from forest fires

The average total emissions from burnt peat soil were 20.9 $MtCO_2e$ annually, which was dominated by emissions from CO_2 (18.9 $MtCO_2\ yr^{-1}$). While emissions from CH_4 are only 2.0 $MtCO_2\ yr^{-1}$ (Table 31).

Table 31. Emisssions from peat fire

Activity	Emissions : peat fire ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Emission : Peat Fire CO_2	18,894,830	3,952,513
Emission : Peat Fire CH_4	2,012,312	501,464
Total emission peat Fire	**20,907,142**	**3,984,197**

Loss of natural forests because of fire also emits non-CO_2 biomass emission, i.e. CH_4 and N_2O. During a reference period, the average annual rate of CH_4 emission from the fire was 3.1 $MtCO_2e\ yr^{-1}$. The average annual N_2O emission from the fire was 1.4 $MtCO_2e\ yr^{-1}$. The highest emission comes from fishpond/aquaculture and estate crop for both gases, as seen in Table 32 and Table 33. Total non-CO_2 emissions from biomass fires was 4.5 $MtCO_2e\ yr^{-1}$.

Table 32. CH_4 Emission from biomass burning that led to deforestation

Forest Strata	Emission CH_4 from Fire ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Primary dry land Forest	58,722	31,996
Secondary dry land Forest	1,099,049	348,760
Primary Mangrove Forest	2,942	5,143
Primary Swamp Forest	100,657	44,155
Secondary Mangrove Forest	8,575	8,248
Secondary Swamp Forest	1,842,109	567,965
CH_4 Emissions	**3,112,053**	**668,794**

Table 33. N_2O Emission from biomass burning that led to deforestation

Forest Strata	Emission N_2O from Fire ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Primary dry land Forest	25,496	11,792
Secondary dry land Forest	477,178	62,515
Primary Mangrove Forest	1,277	2,207

Primary Swamp Forest	43,703	14,961
Secondary Mangrove Forest	3,723	3,457
Secondary Swamp Forest	799,795	94,954
N_2O Emissions	1,351,172	115,343
Total non-CO_2 emissions	**4,463,225**	**678,668**

6.2.1.4. Emissions from mangrove conversion

During the reference period, emissons from mangrove conversion were accounted for 433.0 thousand tCO_2e yr^{-1} from conversion to fishponds and 122.3 thousand tCO_2e yr^{-1} from conversion to other cultivated lands, totaling 554.2 thousand tCO_2e yr^{-1} (Table 34).

Table 34. Emission: mangrove soil

Activity	Emission: Mangrove Soil (tCO_2e yr^{-1})	SE (tCO_2e yr^{-1})
Mangrove converted to fish pond	431,923	113,144
Mangrove converted to cultivated land	122,287	25,616
Mangrove soil emissions	**554,210**	**116,007**

6.2.2. Emissions from forest degradation

6.2.2.1. Biomass emissions

The average annual historical emission from AGB due to forest degradation from 2006/2007 – 2019/2020 amounts to approximately 38.5 $MtCO_2e$ yr^{-1} (*see* Table 35). About 98% (34.0 $MtCO_2e$ yr^{-1}) of this figure was accounted for by emissions from primary dryland forest degradation. Forest degradation of peat swamp and mangrove forests emitted approximately 2.5 million tCO_2e yr^{-1} and 2.0 million tCO_2e yr^{-1}.

Table 35. Emission from forest degradation

Activity	Emission: Forest Degradation: natural forest (tCO_2e yr^{-1})	SE (tCO_2e yr^{-1})
Primary dryland forest – secondary dryland forest	34,045,684	6,424,945
Primary mangrove forest – secondary mangrove forest	1,996,844	1,911,787
Primary swamp forest – secondary swamp forest	2,470,716	1,331,545
Total emission forest degradatioan - biomass	**38,513,245**	**6,834,315**

6.2.2.2. Peat decomposition

The average soil emission from peat decomposition in degradation areas was 183,7 thousand tCO_2e annually. More than 87% of the emissions are arising from degradation of primary swamp forests into secondary swamp forests (161.0 thousand $tCO_2e\ yr^{-1}$) (Table 36).

Table 36. Emission from Forest Degradation in peatlands

Activity	Emission: Forest Degradation: peat ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Primary dryland forest – secondary dryland forest	17,054	10,157
Primary mangrove forest – secondary mangrove forest	5,664	5,558
Primary swamp forest – secondary swamp forest	160,973	46,769
Total Emission forest degradation - peat dec	**183,692**	**48,181**

6.2.2.3. Emissions from biomass burning

The average total emissions from biomass burning that led to forest degradation were 21.1 thousand tCO_2e annually, including CH_4 emission of 14.7 thousand $tCO_2e\ yr^{-1}$ and N_2O emission of 6.4 thousand $tCO_2e\ yr^{-1}$. The highest emission comes from the degradation of primary dry land forest for both gases, as seen in Table 37 and Table 38. Total non-CO_2 emissions from biomass burning was 21.1 thousand $tCO_2e\ yr^{-1}$.

Table 37. Non-CO_2 Emission from fires (CH_4)

Activity	Emission Non-CO_2 from fire (CH_4) ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Primary dryland forest – secondary dryland forest	10,857	3,877
Primary mangrove forest – secondary mangrove forest	270	300
Primary swamp forest – secondary swamp forest	3,615	1,580
Total emission CH_4 - fire	**14,742**	**4,197**

Table 38. Emission Non-CO_2 from fire (N_2O)

Activity	Emission Non-CO_2 from fire (N_2O) ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Primary dryland forest – secondary dryland forest	4,714	995
Primary mangrove forest – secondary mangrove forest	117	126
Primary swamp forest – secondary swamp forest	1,569	534
Total emission N_2O - fire	**6,401**	**1,136**
Total non-CO_2 emission	**21,142**	**4,348**

6.2.3. Removals from ECS

6.2.3.1. Biomass removal

The average biomass removal from EFCS activities from 2006 to 2020 was approximately -16.7 million $tCO_2e\ yr^{-1}$. The removal was derived from the deduction of the last year period (T_1) carbon stock, i.e. 31.2 million $tCO_2e\ yr^{-1}$ with the initial (T_0) carbon stock, i.e. 14.5 million $tCO_2e\ yr^{-1}$ (Table 39 and Table 40).

Table 39. Initial carbon stock before forest gain (T_0)

Land cover type	Initial stock (T_0) ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Dry shrub	10,327,939	3,174,103
Estate crop	428,064	567,146
Settlement	1,608	7,286
Bare ground	54,346	50,397
Savanna and Grasses	84,002	77,788
Open water	-	
Wet shrub	1,077,232	578,878
Pure dry agriculture	149,716	185,580
Mixed dry agriculture	2,357,944	1,464,695
Paddy field	45,342	82,290
Fish pond/aquaculture	-	
Port and harbour	-	
Transmigration areas	3,975	28,048
Mining areas	-	
Open swamps	-	
Total initial CS (T_0)	**14,530,169**	**3,595,505**

Table 40. Forest carbon stock of the last period (T_1)

Type of Enhance of Forest Carbon Stock	Potential Stock - Forest (T_1) ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Secondary dry land Forest	17,749,213	5,073,403
Secondary Mangrove Forest	564,195	427,389
Secondary Swamp Forest	4,124,424	2,381,140
Plantation forest	8,797,979	3,289,022
Total potential CS (T_1)	**31,235,810**	**6,512,263**
Enhance of forest carbon stock Nett (T_0-T_1)	**(16,705,642)**	**7,438,900**

6.2.3.2. Peat decomposition on enhancement of forest carbon stock areas

Apart from biomass removals, EFCS on peatlands will mostlikely emit GHG emissions from peat decomposition, unless it is changed into a water-logged land cover class or primary forest class. Drained peatlands due to canals for accessibility or drainage will emit GHG emissions from the oxidation of dried organic soil. Annual emission from peat decomposition in the EFCS areas was 562 thousand tCO_2e annually, derived from the average of T_0 (485 thousand tCO_2e) and T_1 (640 thousand tCO_2e) annual emissions (Table 41 and Table 42).

Table 41. Emission from peat decomposition in the EFCS areas in T_0

Strata	Emission peat decomposition deforested T_0 ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Dry shrub	23.040	21.705
Estate crop	12.097	13.976
Settlement	140	1.656
Bare ground	154.883	66.119
Savanna and Grasses	4.324	9.250
Open water	-	-
Wet shrub	285.822	92.131
Pure dry agriculture	1.281	5.043
Mixed dry agriculture	3.621	9.308
Paddy field	21	558
Fish pond/aquaculture	-	-
Port and harbor	-	-
Transmigration areas	4	291
Mining areas	273	2.756
Open swamps	-	-
Emission peat decomposition all strata T_0	**485.232**	**117.163**

Table 42. Emission from peat decomposition in the EFCS areas in T_1

Forest Strata	Emission Peat Decomposition Deforested T_1 ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Primary dryland forest	182	1.603
Secondary dryland forest	5.515	8.852
Primary mangrove forest	317	142
Primary swamp forest	1.812	504
Secondary mangrove forest	3.689	7.234
Secondary swamp forest	74.815	33.627
Plantation forest	554.070	154.009
Emission peat decomposition all strata T_1	**640.401**	**162.003**
Peat Decomposition Emission (T1+T2)/2	**561,731**	**140,422**

6.3. Uncertainty Analysis

Based on the uncertainty calculation using the Monte Carlo simulation, we found that overall average emissions were 192.8 million tCO_2e with the lower and upper 95% confidence levels of 156.3 million tCO_2e and 229.8 million tCO_2e, respectively (Table 43). The overall uncertainty of the emission estimate was 19.0%. The largest source of uncertainty was from peat decomposition in forest degradation areas, with an uncertainty of 51.1%. The greatest precision has been the estimated peat emissions from deforestation with just 19.7% uncertainty, thanks to the high accuracy of activity data and the high tier data of biomass stock measurement. Since these figures were derived from the Monte Carlo Simulation, they may change when we repeat the simulation.

Table 43. Uncertainty analysis results of emission estimates using Monte Carlo simulation

Activity	Mean Emissions ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)	Lower bound 95% C.I.	Upper bound 95% C.I.	Half width 95% C.I.
Biomass emission from deforestation	139,578,392	15,479,627	109,704,836	170,234,575	21.7%
Peat decomposition emission (deforestation)	4,781,796	483,152	3,877,120	5,765,424	19.7%
Peat fire emission (deforestation)	20,867,787	4,011,393	13,249,655	28,893,728	37.5%
Fire emission from biomass and DOM(deforestation)	4,459,690	705,801	3,109,803	5,879,758	31.1%
Mangrove soil emissions (deforestation)	555,278	115,796	331,180	787,705	41.1%
Biomass emission from forest degradation	38,523,374	6,713,411	25,530,559	51,802,352	34.1%
Peat decomposition emission (forest degradation)	183,297	47,865	97,855	285,095	51.1%
Fire emission from biomass and DOM (forest degradation)	21,149	4,963	12,375	31,483	45.2%
Biomass removal from enhancement of forest carbon stock (EFCS)	(16,759,367)	6,959,659	(30,549,442)	(3,364,143)	81.1%
Peat decomposition emission (EFCS)	561,731	140,422	292,937	847,988	49.4%
Total emissions from deforestation, forest degradation and EFCS	**192,773,127**	**18,838,198**	**156,335,828**	**229,764,698**	**19.0%**

6.4. Constructed National Forest Reference Level

Annual historical emissions from deforestation, forest degradation and enhancement of forest carbon stock from 2006 to 2020 were 192.9 $MtCO_2e\ yr^{-1}$. Emissions from deforestation contribute the most and accounts for 75.3% of the total absolute emissions and removals (Table 44). Absolute contribution of forest degradation and enhancement of forest carbon stocks to the cinstructed FRL are 17.1% and 7.6%, respectively.

The three largest single emission sources are coming from biomass emission due to deforestation, biomass emission from forest degradation and peat fire emissions from deforestation, which accounts for 139.6 $MtCO_2e$, 38.5 $MtCO_2e$, and 20.9 $MtCO_2e$ or equals to absolute contribution of 61.7%, 17.0% and 9.2%, respectively (Figure *3*). Biomass removals from enhancement of forest carbon stock accounts for -16.7 $MtCO_2e$, which shares absolute contribution of 7.4% of total FRL.

Table 44. Constructed forest reference level

REDD+ Activity	Activity	Mean	Standard error	Uncertainty (%)	Absolute contribution
Deforestation	Deforestation Emission - Biomass	139,646,704	21,637,882	30.4	75.3%
	Peat Decomposition Emission	4,774,760	384,232	15.8	
	Peat fire emission	20,907,142	3,984,197	37.4	
	AGB+DOM fire emission	4,463,225	678,668	29.8	
	Mangrove soil emissions	554,210	116,007	41.0	
Forest Degradation	Forest degradation emission - Biomass	38,513,245	6,834,315	34.8	17.1%
	Peat Decomposition Emission	183,692	48,181	51.4	
	AGB+DOM fire emission	21,142	4,348	40.3	
Enhancement of Forest Carbon Stock	Enhance of forest carbon stock (EFCS)	(16,705,642)	7,438,900	87.3	7.6%
	Peat Decomposition Emission	562,816	199,930	69.6	
Total emission deforestation, forest degradation and EFCS		**192,921,295**	**24,223,560**	**24.6**	

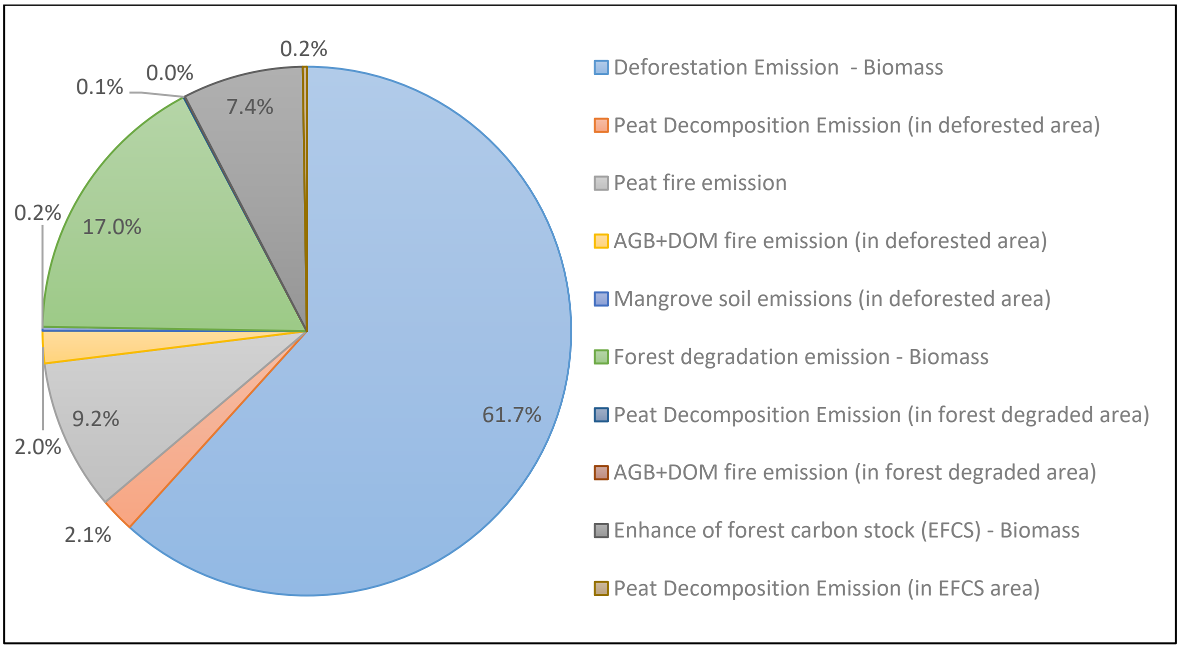

Figure 3. *Absolute contribution of the annual emissions and removals from deforestation, forest degradation, enhancement of forest carbon stocks and the associated emissioms from peat decomposition, peat degradation and mangrove conversion (in percentage)*

The constructed FRL values were derived from the original input of the estimated means and standard errors, not from the results of Monte Carlo Simulation (see sub chapter 6.3). The mean constructed FRL was 192,921,295 $tCO_2e\ yr^{-1}$, slightly different to the result from the Monte Carlo Simulation 192,773,127 $tCO_2e\ yr^{-1}$ (around 0.08 % difference). The overall uncertainty of the constructed FRL was 24.6%, higher than the overall uncertainty estimated from the Monte Carlo Simulation (around 19%), which change every time the simulation is repeated.

Compared to the 1st FREL, emissions from peat decomposition in this version are much less due to inherited emissions exclusion. Total emission from peat decomposition was only 5.5 $MtCO_2$ yr^{-1}, compared to about 226 $MtCO_2$ yr^{-1} in the 1st FREL. Emissions from peat decomposition included in this calculation are only emissions directly associated with deforestation, forest degradation and enhancement of forest carbon stock. An insignificant emission from mangrove soil and biomass burning represents only less than 1% and 3% to the total absolute FRL, respectively.

The new and significant activities included in this submission have been enhanced for forest carbon stocks and peat fires. The contribution from the biomass removal of enhancement of forest carbon stocks the 4th largest with absolute contribution of -7.4%, which accounts for -16.7 $MtCO_2e$. Emissions from peat fires, which was not included in the 1st FREL, represent more than 9% of the total absolute emissions.

This calculation followed the guidelines and conformed to the standard established by the COP decision, including the TACCC of data. The constructed FRL serves as a basis to assess emission reductions resulting from post 2020 REDD+ activities. The reference level is based on the 14 years of historical emissions and will be projected in 10 years. In case of new data and better methodology are available, the FRL possibly be updated in 5 years.

7. Description of policies and plans and their implications to the constructed Forest Reference Level (FRL)

7.1. Policy interventions in constructing FRL

Forest restoration and rehabilitation have become substantial efforts to achieve national commitment to reducing GHG emissions through the forest carbon stock enhancement. Forestry Law number 41/1999 stated that the objective of rehabilitation is to restore, protect and improve the carrying capacity, productivity, and roles in environmental services of the degraded lands. Currently, there is about 30 million hectares of unproductive land, out of which 7.7 million hectares are heavily degraded (MoEF, 2021a). Indonesia aims to accelerate restoring degraded land to protect environmental services. In addition, acceleration of the establishment of forest plantations in unproductive land to meet the increasing wood demand and reduce pressure on natural forest, has also been prioritized. Also, the expansion of mandate of the National Agency for Peat Restoration (now National Agency for Peat and Mangrove Restoration) to include mangrove restoration program suggests that the restoration of degraded peatland and mangrove has become an important agenda for Indonesia to further reduce GHG emissions from wetlands and at the same time improve the quality of environmental service as well as local livelihood.

Conversion of carbon rich peat forest and mangrove ecosystems contributes significantly to GHG emissions. Specific regulations on wetland management have been enacted to further protect the carbon-rich ecosystems (e.g., MoEF regulation number 15/2017 that reinforces water management of peatland in concessionaires; MoEF Regulation No.P.16/2017 that guides restoring peat ecosystem functions). During the prolonged dry season, drained peatlands are susceptible to fires, consuming organic soils and releasing large amount of GHG emissions. Controlling land and forest fire has been mandated by the government to all land managers through several regulations (e.g., MoEF Regulation No.P.77/2015 on Handling of Fire-Tracked Areas in Concession Areas; Presidential Instruction No.11/2015 regarding Improvement of Forest and Land Fire Control; Presidential Instruction No. 3/2020 regarding on the land and forest fires control). Failing to control the fires could expose to sanctions. In the presence of these policies, the FRL also includes emissions from peat decomposition and peat fires and non-CO_2 emissions from biomass burning.

7.2. National programs on climate change mitigation and REDD+ implementation

Since the first submission of Indonesia's Forest Reference Level in 2016, the Government of Indonesia has ratified the Paris Agreement (PA) through Indonesian Act No 16/2016. Furthermore in 2016 Indonesia has submitted its commitment through the Nationally Determined Contribution (NDC) to reduce greenhouse gas emissions with an unconditional target of 29% and conditional target (with international support) of up to 41% compared to business as usual (BAU) emission levels by 2030 (MoEF, 2016b).

Five years after the first NDC submission, Indonesia has reinforced its climate commitments through the Updated NDC in 2021 with fair emissions reduction targets and strengthened alignment between the country's climate and development objectives (MoEF, 2021a). With the strong commitments on climate change mitigation and adaptation, the updated NDC reflects Indonesia's adoption of the established Paris Agreement Rule Book (Katowice Package) into the national context to ensure effectiveness and efficiency in implementing the agreement. Furthermore, this commitment on adaptation ambitions was enhanced through programs, strategies, and actions aiming to achieve economic, social, ecosystem and landscape resilience. This commitment also communicates progress and achievements in line with the national development and long-term visions.

In the context of long-term visions, the Government of Indonesia has set up the Long-Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR) 2050 (MoEF, 2021b). The LTS-LCCR was designed by taking into account the balance between emission reductions and economic development, and putting emission reductions, economic growth, equity and climate resilience development as an integral part of the LTS-LCCR objectives. In line with these objectives, Indonesia will increase its GHG abatement ambitions by achieving a national peak of GHG emissions by 2030 in the forestry and other land use (FOLU) sector, with an achievement of 540 $MtCO_2e$ by 2050, and by exploring opportunities to achieve a faster progress towards its net-zero emissions by 2060 or earlier.

Significant efforts to reduce FOLU sector emissions and convert them to netsinks by 2050 through the current policy scenario mechanism and by 2030 through a low carbon scenario compatible with Paris Agreement targets are strengthened through the Operational Plan of Indonesia's Forestry and Other Land Use (FOLU) Net Sink 2030 (MoEF 2022). However, the success of this program will depend on the success of the following actions:

(i) Reducing emissions from deforestation and forest degradation by expanding protected natural forests, increasing community participation, and strengthening partnerships with the community in forest management.
(ii) Increasing the carbon sequestration capacity of natural forests by reducing the forest degradation and increasing its regeneration through enrichment or implementation of a sustainable forest management system.
(iii) Increasing the carbon sequestration of land systems by maximising the use of unproductive or low carbon land use for the development of forest plantations, and other perennials or industrial crops.
(iv) Reducing emissions from fires and peat decomposition by improving peatland management systems.
(v) Law enforcement.

In addition, the Government of Indonesia has taken significant steps toward improving the management of forest resources while also achieving emission reduction target by issuing a number of regulations. Some key regulations include:

1. Government Regulation No. 104 of 2015 regarding procedures for changing in designation and functions of forest areas, which ban the conversion of

forested lands (production forest) in forest area for APL (land designed for other use), except in the provinces where the non-forested lands in the production forest are not available.

2. Presidential Instruction No. 8 of 2018 regarding postponement and evaluation of oil palm plantation permits, which confirmed a moratorium on new palm oil development and ordered a review of existing plantations. This new moratorium, along with other forest protection measures could create a much-needed window of opportunity to undertake critical forest governance and land use reforms.
3. Presidential Regulation No. 77/2018 on the establishment of Environmental Fund Management Agency (BPDLH). An agency to manage funds for climate change management.
4. Presidential Instruction No. 5 of 2019 regarding termination of new permit and improvement of primary natural forest and peatland governance. This regulation leads to permanent protection of more than 66 million hectares of mostly primary forests and peatlands, by avoiding new licenses.
5. Presidential Regulation No. 120 of 2020 regarding the Peatland and Mangrove Restoration Agency to support the GoI commitment to accelerate peatlands and mangroves rehabilitation. The Agency has a mandate to restore more than 2.6 million hectares of degraded peatlands in seven provinces to prevent future fires, and to rehabilitate 600,000 hectares of degraded mangroves in six provinces.

8. Opportunities for Improvement

The FRL was developed based on the current data and knowledge in national circumstances, capacities and capabilities. The limitation of the analysis is primarily related to the availability, clarity, accuracy, completeness, and comprehensiveness of the data. Further improvements may be made to the current estimates as more and better data and methodology become available, noting the importance of appropriate and predictable support as referred to in paragraph 71 of Decision 1/CP.16.

Several aspects of potential improvement were identified, including the inclusion of additional REDD+ activities, improved accuracy of emission factors, and improved activity data (Table 45). Other REDD+ activities that are not included in the submission are sustainable management of forest and the role of conservation. The inclusion of these activities may require a robust and accurate methodology for monitoring the annual emissions and removals. It is also crucial to avoid double counting, for example, monitoring of forest degradation may overlap with sustainable management of forest. A more detailed emission factor and high-resolution activity data may be able to explore the additionality of emission reductions that do not overlap.

Table 45. List of improvements plan

Type of Improvement	Plan of Improvement	Requirement or Challenges
Inclusion of REDD+ activities	Inclusion of SFM and role of conservation	A robust approach to monitoring SFM emissions and removal, and role of conservation
Inclusion of other pools and gases	• Inclusion of dead organic matters in the estimation of emissions and removals from deforestation, forest degradation and EFCS. • Inclusion of soil organic carbon in estimating emissions from deforestation and enhancement of forest carbon stocks	Compilation of new studies
EF improvement	• Tier 2 of EF for mangrove conversion to cultivation • Removal factors of rehabilitation efforts • Peat depth fires based on fire frequency • EF and baseline for peat rewetting activity	Compilation of new studies
AD improvement	• AD for ECS from forest remaining forest	Improved methods for AD monitoring based on remote sensing

Type of Improvement	Plan of Improvement	Requirement or Challenges
	• Revisiting older forest and land cover maps for accuracy assessment based on the updated methods • Rewetting of peatlands could have a significant impact on emission reduction and the mapping of large-scale reading AD mapping	

Improvement in the accuracy of emission factors is expected to be one of the prioritized plans of activities. Improving emission factors related to peatland rewetting and mangrove rehabilitation through collation and promotion of new relevant studies should be highly rewarded and contribute significantly to the accuracy of the overall estimates.

The inclusion of other carbon pools and gases is considered an excellence strategy to be consistent with the principle of completeness. Dead organic matter is still excluded from assessing biomass emissions associated with deforestation and forest degradation. Other non-CO_2 gases resulting from peat decomposition, such as CH_4 and N_2O, could be included in the next improvement.

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Annexes

Annex 1. Forest and land cover data

Land cover map of the Ministry of Forestry (MoFor) of Indonesia

The Directorate General of Forestry Planning of the Ministry of Forestry (MoFor) has used satellite data, particularly Landsat, since the 1990s, for land cover mapping of Indonesia. The wall-to-wall forest monitoring system was first established in 2000 and was initially updated every three years based on data availability, due to problems of clouds and haze, and cost-effectiveness. At least 217 Landsat scenes are required to cover the entire land area of Indonesia, excluding additional settings to minimize/remove clouds and the presence of haze. Until 2006, other data sets such as SPOT Vegetation 1000 meters and MODIS 250 meters were used as alternatives, especially when the purchased Landsat data of MoFor were not yet ready for processing and classification processes.

More complete data became available around 2009, following the change in the Landsat data policy of the United States Geological Survey (USGS) in 2008 which made Landsat data freely available on the internet. The new Landsat data policy automatically benefits Indonesia by increasing the number of scenes available for supporting the mapping system. In 2013, MoFor started to use the newly launched Landsat 8 OLI to monitor Indonesian land cover condition and placed the Landsat 7 ETM+ as a substite or cloud removal. The abundance of data available through the free download allowed Indonesia to change mapping interval from three-year to an annual. Up to now, land cover data is available for the years of 1990, 1996, 2000, 2003, 2006, 2009, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, and 2020.

To maintain product continuity and further improve the work, a collaboration between LAPAN (National Space Agency) for Landsat data preparation and MoFor/MoEF for the classification process is a significant key for developing national forest monitoring system (NFMS) is known as the Simontana (*Sistem Monitoring Hutan Nasional*) (MoFor, 2014). Both institutions have a Memorandum of Understanding on the work since 2004 which was recently updated.

The NFMS products are available online at https://nfms.menlhk.go.id/peta as online interactive and links to website of map server (http://dbgis.menlhk.go.id/arcgis/rest/services/Simontana for land cover of 1990-2018 period; https://dbgis.menlhk.go.id/arcgis/rest/services/KLHK/Penutupan_Lahan_Tahun_2019/MapServer for land cover of 2019; https://dbgis.menlhk.go.id/arcgis/rest/services/KLHK/Penutupan_Lahan_Tahun_2020/MapServer for land cover of 2020). The data also can be access via the One Map Web GIS, at http://tanahair.indonesia.go.id (Geospatial Information Agency Republic of Indonesia, 2010) or https://portalksp.ina-sdi.or.id/ (Coordinating Ministry for Economic Affair). The website is part of the geospatial portal under the One Map Policy.

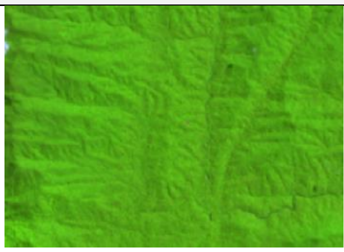
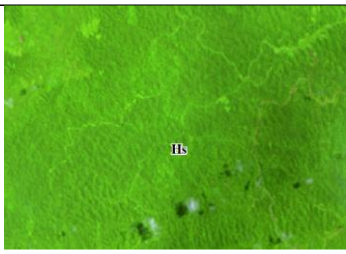
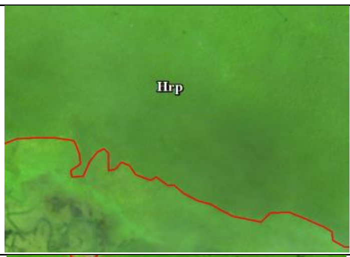
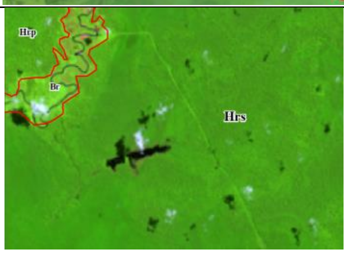
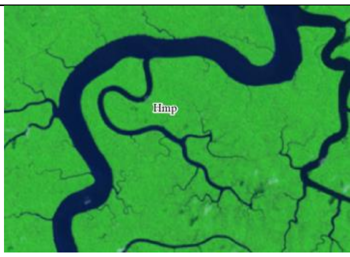
The historical development of Indonesia land cover mapping can be divided into three periods. During Period 1, which correspond to the period preceding 2000, all available data including analogue data and hard copies of the Landsat scenes, were delineated manually and digitised. For Landsat, most of scenes available electronically in CCT format or hard copy format did not have the same year interval. Thus, during the 1st period, the data used to generate the land cover maps came in various conditions and formats. Outputs from the 1st period were generated under the NFI activity and subsequently published on Holmes (2000, 2002). Period 2 (2000-2009) is the period of using merely digital data. However, the data were classified manually which is a time-consuming process and delayed the product delivery, especially as work experiences in wall-to-wall mapping were still limited. Permanent cloud cover issues in some of Indonesian regions and thus data unavailability for these areas also slowed down the process. An alternative approach by using SPOT Vegetation 1000 metres and MODIS 250 metres was applied for immediate reporting. In 3rd period (starting in 2009), data availability was no longer a constraint, and Landsat imagery was then the only data source. Significant improvements were carried out during the 2nd period (2006) and became a major concern in the early part of 3rd period (2009); the improvements included the migration of each layer of the time-sequential land cover data into a single geodatabase. Geodatabase is a solution to improve interdependency and consistency among the different layers. Now, efforts to overcome the time-consuming manual classification process are the primary concern.

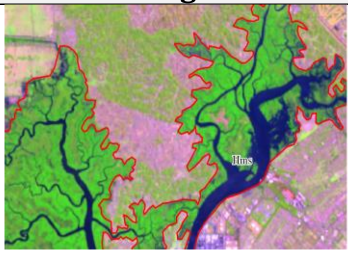
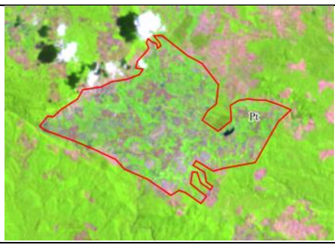
Summary of SOP for interpretation of medium resolution satellite imagery for national land cover updated

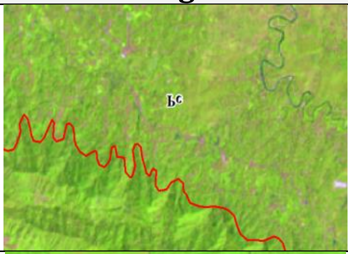
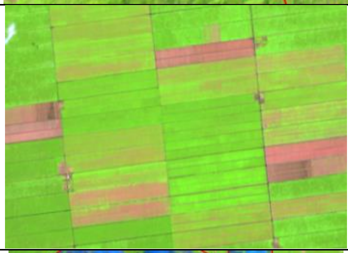
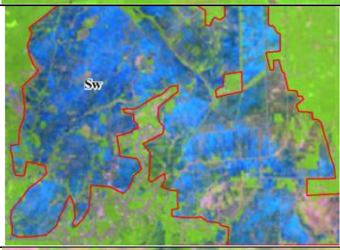
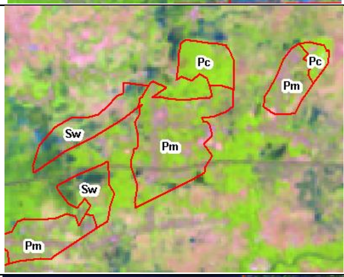
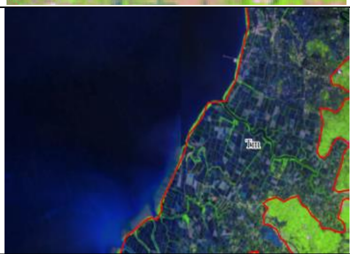
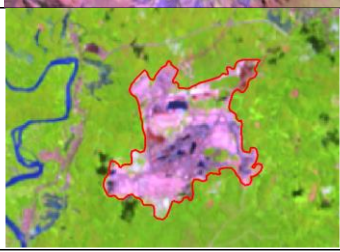
Indonesia's land cover mapping uses the visual interpretation method with Minimal Mapping Unit (MMU) 6.25 ha that carry out using GIS software. This method uses keys of interpretation including colour, tone, texture, shape, pattern, shadow, site, and association to detect the object. To minimize the error of classification due to the varies in land cover and different national circumstances, MoEF has established the SOP for land cover interpretation using the medium-resolution imagery that also contains the monogram of land cover types. Land cover data update are conducted annually that uses the interdependency method, where land cover of T1 was updated based on Landsat image of T1 to update the land cover of T0. The delineation based on the different of object on the image.

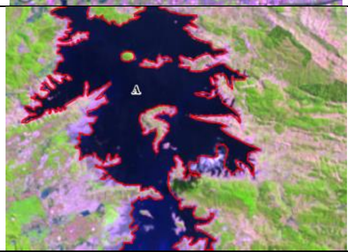
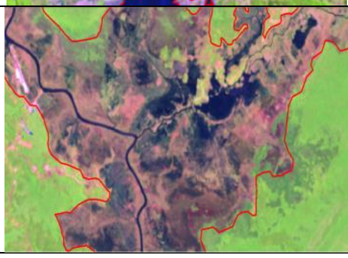
The land cover map of Indonesia consists of 23 classes, including six classes of natural forest, 1 class of plantation forest, 15 classes of non forest, and one class of clouds-no data. The 23 classes are described in Table Annex 1.1 (refer to SNI 7645-2010, Margono *et al*. 2016); with the series of monogram for those 23 classes is described in (MoFor, 2003). A monogram is a detailed explanation or class description completed by sample image subsets of different band and field pictures.

Table Annex 1.1. The 23 land cover classes of Indonesia and their description

No	Classes	Monogram	Description
	Forest		
1	Primary dryland forest		Natural tropical forests growing on non-wet habitat including lowland, upland, and montane forests. The class includes heath forest and forest on ultramafic and limestone, as well as coniferous, deciduous and mist or cloud forest, which is not (or low) influenced by human activities or logging.
2	Secondary dryland forest		Natural tropical forest growing on non-wet habitat including lowland, upland, and montane forests that exhibit signs of logging activities indicated by patterns and spotting of logging (appearance of roads and logged-over patches). The class includes heath forest and forest on ultramafic and limestone, as well as coniferous, deciduous and mist or cloud forest.
3	Primary swamp forest		Natural tropical forest growing on wet habitat in swamp form, including brackish swamp, marshes, sago and peat swamp, which is not or low influenced by human activities or logging.
4	Secondary swamp forest		Natural tropical forest growing on wet habitat in swamp form, including brackish swamp, marshes, sago and peat swamp that exhibit signs of logging activities indicated by patterns and patches of logging (appearance of roads and logged-over patches).
5	Primary mangrove forest		Wetland forests in coastal areas such as plains that are still influenced by the tides, muddy and brackish water and dominated by species of mangrove and Nipa (*Nipa frutescens*), which is not or low influenced by human activities or logging.

No	Classes	Monogram	Description
6	Secondary mangrove forest		Wetland forests in coastal areas such as plains that are still influenced by the tides, muddy and brackish water and dominated by species of mangrove and Nipa (*Nipa frutescens*), and exhibit signs of logging activities, indicated by patterns and patches of logging activities.
7	Plantation forest		The appearance of the structural composition of the forest vegetation in large areas, dominated by homogeneous trees species, and planted for specific purposes. Planted forest include areas of reforestation, industrial plantation forest and community plantation forest.
	Non Forest		
8	Dry shrub		Highly degraded logged-over areas on non-wet habitat that are in an ongoing process of succession but have not yet reached a stable forest ecosystem, with naturally scattered trees or shrubs
9	Wet shrub		Highly degraded logged-over areas on wet habitat that are in an ongoing process of succession but have not yet reached a stable forest ecosystem, with naturally scattered trees or shrubs
10	Savanna and Grasses		Areas with grasses and scattered natural trees and shrubs. This is typical of natural ecosystem and appearance on Sulawesi Tenggara, East Nusa Tenggara, and the southern part of Papua Island. This type of cover could be on wet or non-wet habitat.
11	Pure dry agriculture		All land covers associated with agricultural activities on dry/non-wet land, such as tegalan (moor), mixed garden and ladang (agriculture fields).

No	Classes	Monogram	Description
12	Mixed dry agriculture		All land covers associated with agricultural activities on dry/non-wet land mixed with shrubs, thickets, and logged-over forest. This type of cover often results from shifting cultivation and its rotation, including on karst.
13	Estate crop		Estate areas that have been planted, mostly with perennials crops or other agricultural trees commodities.
14	Paddy field		Agriculture areas on wet habitat, especially for paddy, that typically exhibit dyke patterns (pola pematang). This cover type includes rain fed, seasonal paddy field, and irrigated paddy fields.
15	Transmigration areas		Kind of unique settlement areas that exhibit association of houses and agroforestry and/or garden at surrounding.
16	Fish pond/aquaculture		Areas exhibit aquaculture activities including fishponds, shrimp ponds or salt ponds.
17	Bare ground		Bare grounds and areas with no vegetation cover, including open exposure areas, craters, sandbanks, sediments, and areas post-fire areas that have not shown sign of regrowth.
18	Mining areas		Mining areas exhibit open mining activities such as open-pit mining including tailing ground.

No	Classes	Monogram	Description
19	Settlement areas		Settlement areas include rural, urban, industrial and other built-up areas with typical appearance.
20	Port and harbour		Sighting of port and harbour that is big enough to be delineated as independent object.
21	Open water		Water bodies including ocean, rivers, lakes, and ponds.
22	Open swamps		Wetland area with few vegetation.
23	Clouds and no-data		Clouds, cloud shadows or data gaps with a size of more than 4 cm^2 at a 100.000 scale display.

The 23 land cover classes are based on physiognomy or biophysical appearance that are sensed by remote sensing data used (Landsat at 30-meter spatial resolution). The class namesorrespond to feature of land uses, such as class of forest plantation or estate crops. However, the identification of object is solely based on the existing appearance in the imagery. Manual-visual classification through on-screen digitizing technique based on key elements of image interpretation was applied as classification method. Several ancillary data sets (including concession boundaries of logging and plantation, forest area boundaries) were utilised during the process of delineation, to integrate additional information valuable for classification.

Since 2017, land cover interpretation uses Landsat mosaic that produced by LAPAN as partner of MoEF. The best image for one year was choosed to build the mosaic. The pre-processing image was conducted including geometric and radiometric correction that resulted in free cloud cover mosaic Analysis Ready Data (ARD) before mosaic processing. Supporting data for the land cover mapping are high-resolution imagery such as SPOT and Google Earth imagery, Sentinel imagery, and spatial data (administration boundary, concession area, peat land). In the middle of land cover mapping process, the field check was also conducted to ensure the land cover type, especially for land cover changes along the mapping process and the uncertain land cover types as well as boundary, for example forest and shrub.

MoEF has started applying a hybrid method that combines visual interpretation method with automated digital analysis data as called de-vegetation data (pixel-based change-detection data for identifying the loss of vegetation). The de-vegetation data were developed based on the NDVI (Normalize Difference Vegetation Index) and OAI (Open Area Index). The data was used to detect the forest cover change faster as well as to improve the accuracy of land cover maps and land cover change data, mainly for deforestation.

Forest degradation (decrease in forest quality) can be monitored at level one, i.e., the change from primary forest to secondary forest assuming the proximity of primary forest (undisturbed forest) to land clearing, road access, settlements, and management, and forest fires.

Annual forest cover from period 2006 – 2020 is presented in Table Annex 1.2. Forest cover is declining from 101.1 million hectare in 2006 to 95.3 million hectare in 2020. Annual net deforestation during that period was 481 thousand hectares annually, mostly from forests in mineral soils (82%). However, net deforestation in peatlands contributes to more than 1% of total peat swamp forests and in mineral soils only less than 0.5% of total forest in mineral soils.

Table Annex 1.2. Annual forest cover from 2006 to 2020 by soil types

Year	Soil Type	NaturalForest						Plantation forest	Total
		Primary dry land Forest	Secondary dry land Forest	Primary Mangrove Forest	Secondary Mangrove Forest	Primary Swamp Forest	Secondary Swamp Forest		
2006	Peat	248.561	263.854	171.422	45.179	2.282.231	5.000.602	264.221	**8.276.071**
	Mineral	40.809.390	38.500.302	1.390.528	1.346.532	3.521.734	3.227.340	3.991.618	**92.787.445**
Total		**41.057.952**	**38.764.157**	**1.561.950**	**1.391.711**	**5.803.965**	**8.227.942**	**4.255.839**	**101.063.515**
2009	Peat	242.535	241.290	170.904	43.781	2.127.357	4.415.954	433.968	**7.675.790**
	Mineral	39.446.643	38.243.586	1.313.591	1.306.054	3.366.328	2.908.956	4.056.732	**90.641.890**
Total		**39.689.178**	**38.484.876**	**1.484.495**	**1.349.835**	**5.493.686**	**7.324.910**	**4.490.700**	**98.317.680**
2011	Peat	242.535	245.731	170.512	43.580	2.090.893	4.163.458	709.062	**7.665.771**
	Mineral	39.127.167	37.980.417	1.309.823	1.308.145	3.343.050	2.772.073	4.119.809	**89.960.485**
Total		**39.369.703**	**38.226.148**	**1.480.335**	**1.351.724**	**5.433.943**	**6.935.531**	**4.828.872**	**97.626.256**
2012	Peat	242.111	240.471	170.510	43.348	2.083.969	4.015.700	807.123	**7.603.232**
	Mineral	39.106.189	37.729.935	1.342.227	1.332.966	3.305.377	2.665.226	4.081.901	**89.563.821**
Total		**39.348.300**	**37.970.405**	**1.512.737**	**1.376.314**	**5.389.346**	**6.680.926**	**4.889.023**	**97.167.053**
2013	Peat	238.765	229.283	166.768	46.799	2.053.401	3.849.725	900.850	**7.485.591**
	Mineral	38.919.688	37.376.357	1.337.474	1.327.156	3.289.043	2.565.650	4.149.666	**88.965.034**
Total		**39.158.453**	**37.605.640**	**1.504.242**	**1.373.954**	**5.342.444**	**6.415.376**	**5.050.516**	**96.450.625**
2014	Peat	238.488	228.564	166.119	47.430	2.045.809	3.746.500	846.284	**7.319.195**
	Mineral	38.830.265	37.232.654	1.332.124	1.325.897	3.271.246	2.548.805	4.193.578	**88.734.570**
Total		**39.068.754**	**37.461.219**	**1.498.243**	**1.373.327**	**5.317.055**	**6.295.305**	**5.039.862**	**96.053.764**

Year	Soil Type	NaturalForest						Plantation forest	Total
		Primary dry land Forest	Secondary dry land Forest	Primary Mangrove Forest	Secondary Mangrove Forest	Primary Swamp Forest	Secondary Swamp Forest		
2015	Peat	232.143	225.245	165.623	48.127	2.021.790	3.515.715	671.796	**6.880.439**
	Mineral	38.189.531	37.493.670	1.313.368	1.335.912	3.251.683	2.488.056	3.989.591	**88.061.811**
Total		**38.421.674**	**37.718.915**	**1.478.991**	**1.384.039**	**5.273.473**	**6.003.771**	**4.661.387**	**94.942.251**
2016	Peat	232.125	233.836	165.313	50.937	1.981.336	3.448.096	657.300	**6.768.944**
	Mineral	39.061.020	36.228.773	1.302.276	1.325.517	3.227.212	2.419.016	3.990.351	**87.554.165**
Total		**39.293.145**	**36.462.609**	**1.467.589**	**1.376.454**	**5.208.548**	**5.867.112**	**4.647.651**	**94.323.109**
2017	Peat	231.507	228.389	164.882	51.918	1.977.760	3.409.447	648.219	**6.712.123**
	Mineral	39.213.597	35.651.642	1.295.337	1.328.536	3.218.154	2.382.558	4.022.548	**87.112.372**
Total		**39.445.104**	**35.880.031**	**1.460.220**	**1.380.454**	**5.195.914**	**5.792.005**	**4.670.767**	**93.824.495**
2018	Peat	264.515	195.763	166.226	52.969	1.921.189	3.366.494	1.145.032	**7.112.187**
	Mineral	39.975.341	34.072.337	1.341.038	1.380.918	3.090.827	3.101.638	4.241.793	**87.203.891**
Total		**40.239.856**	**34.268.100**	**1.507.263**	**1.433.886**	**5.012.016**	**6.468.132**	**5.386.825**	**94.316.078**
2019	Peat	297.290	189.564	166.662	60.020	1.874.434	3.470.873	1.178.750	**7.237.592**
	Mineral	40.201.485	34.418.710	1.422.964	1.350.663	2.985.168	3.450.367	4.277.113	**88.106.470**
Total		**40.498.775**	**34.608.274**	**1.589.627**	**1.410.683**	**4.859.601**	**6.921.239**	**5.455.863**	**95.344.062**
2020	Peat	296.832	189.711	166.477	60.242	1.872.233	3.453.664	1.181.241	**7.220.400**
	Mineral	39.837.446	34.732.969	1.426.199	1.373.637	2.980.291	3.445.979	4.279.390	**88.075.910**
Total		**40.134.277**	**34.922.680**	**1.592.676**	**1.433.878**	**4.852.524**	**6.899.644**	**5.460.631**	**95.296.310**

Accuracy assessment of land cover maps

Accuracy assessments of land cover maps of 1990, 1996, 2000, 2003, 2006, 2009, 2011, 2012, 2013, 2014, 2015, and 2016 were carried out by the Ministry of Environment and Forestry (KLHK, 2020). The calculation of land cover maps accuracy assessment has continued for 2017, 2018, 2019, and 2020. The 23 land cover classes were categorized into two land cover categories, namely forest class and non-forest categories. Forest classes include natural forest land cover classes (primary dry land, secondary dry land forest, primary mangrove forest, secondary mangrove forest, primary swamp forest and secondary swamp forest) and plantation forest. Non-forest classes include plantation land cover classes, shrubs, swamp scrub, savanna/grasslands, agriculture, dry land, mixed dry land agriculture, rice fields, ponds, settlements, transmigration settlements, open land, mining, bodies of water, swamps, airports/ports, and clouds.

The accuracy assessment of land cover maps was performed based on randomly distributed reference points and the reference data for validating the land cover maps. The reference data sources used in this analysis were satellite images with a higher resolution than the satellite imagery used as a data source for land cover mapping, or better temporal resolution with multiple acquisitions. The total number of reference points used in the analysis for the period 1990-2016 were 10,000 sample points, randomly and proportionally distributed to all islands in Indonesia (Table Annex 1.3). While the land cover accuracy assessment for 2017-2020 was used 5,000 sample points.

Tabel Annex 1.3. Number of reference points, distributed randomly and proportionally to all islands

ISLAND	TOTAL AREA (HECTARES)	AREA PERCENTAGES (%)	SAMPLING POINT
PAPUA	41,404,459	21.75	2,172
JAWA	13,515,938	7.1	702
KALIMANTAN	53,644,950	28.18	2,828
MALUKU	7,862,088	4.13	413
BALI NUSA TENGGARA	7,405,211	3.89	381
SULAWESI	18,731,948	9.84	987
SUMATERA	47,800,734	25.11	2,517
TOTAL	**190,365,329**	**100**	**10,000**

Accuracy was estimated using the error matrix, Kappa coefficient and accuracy. The accuracy of each period of land cover data was measured and the results are calculated using an error matrix as shown in Table Annex 1.4. This table shows an example of calculating accuracy using the Single Point Centroid land cover data validation method. The calculated accuracy values include user accuracy and producer accuracy for forest (F) and non forest (NF) classes and the overall accuracy of the data.

Tabel Annex 1.4. Error matrix of 2016 land cover map

Forest and Non Forest Categories		Reference Data		Total	User Accuracy
		F	NF		
Land Cover Map	F	4,303	334	4,637	92.8
	NF	472	4,891	5,363	91.2
	Total	**4,775**	**5,225**	**10,000**	
Producer Accuracy		**90.1**	**93.6**		
Overall Accuracy		**91.9**			

Note: F (Natural Forest); NF (Non-Forest)

Tabel Annex 1.5. Overall accuracies of land cover maps for each monitoring period.

Period Year	Land Cover	Accuracy		
		User	Producer	Overall
1990	Forest	90.6	91.2	89.1
	Non-Forest	86.7	85.8	
1996	Forest	90.7	90.1	88.8
	Non-Forest	86.2	87	
2000	Forest	92.6	91	91.2
	Non-Forest	89.5	91.3	
2003	Forest	92.2	91.6	91.4

Period Year	Land Cover	Accuracy		
		User	Producer	Overall
	Non-Forest	90.5	91.2	
2006	Forest	91.8	91.4	91.4
	Non-Forest	90.9	91.3	
2009	Forest	92.2	91.2	91.7
	Non-Forest	91.2	92.2	
2011	Forest	92.1	91.5	91.9
	Non-Forest	91.7	92.3	
2012	Forest	92.1	91.8	92.1
	Non-Forest	92.1	92.4	
2013	Forest	92.1	91.7	92.1
	Non-Forest	92.2	92.5	
2014	Forest	91.8	91.9	92.1
	Non-Forest	92.5	92.4	
2015	Forest	91.6	91.9	92.2
	Non-Forest	92.5	92.3	
2016	Forest	92.8	90.1	91.9
	Non-Forest	91.2	93.6	
2017	Forest	94.3	92.1	93.5
	Non-Forest	92.8	94.8	
2018	Forest	95.7	94.0	95.0
	Non-Forest	94.3	95.9	
2019	Forest	96.2	94.8	95.3
	Non-Forest	94.3	95.9	
2020	Forest	97.8	91.7	94.7
	Non-Forest	91.9	97.9	

Following the latest developments on data availability, MoFor has been refining the national land cover classification maps, from the 1990s to 2013, and plans to update deforestation data over more than two decades using the refined land cover data set. MoFor has collected and archived more than 10,000 Landsat scenes from the entire country dating back from the early 1990s onwards. Although targeting the whole observation period from 1990 to 2013, the first version of refinement (up to July 2014) focused on data from 2009 onwards. In addition, the deforestation rate from 2000 to 2003 that was generated using the alternative data of SPOT Vegetation (2000-2005) has been replaced with deforestation rates derived from Landsat. Therefore, the land cover data used in this submission are those based on the first refinement.

Comparison with other datasets

There are two independent studies used for comparison purposes to demonstrate the reliability of the MoFor data used in this FREL submission, as well as to give scientific background to the presented results. Those are the study of Margono *et al.* (2014) and the study of LCCA-LAPAN.

Land Cover map of Margono et al. (2014)

The study of Margono *et al.* (2014) has been published in the Journal of Nature Climate Change (NCC), available online since June 2014. The study is part of the global mapping system of Hansen *et al.* (2013) with specific modifications for the national scale (Indonesia). The study generates three main land cover classes: primary intact forest, primary degraded forest, and non-primary forest (other land covers). Referring to the supplementary material of the NCC submission, primary forests were defined as all mature forests of 5 ha or more, to the extent that retains their natural composition and structure and has not been completely cleared in recent history (at least 30 years in age). The primary forest is disaggregated intointact (undisturbed type) and degraded (disturbed type). Intact primary forest has a minimum area unit of 500 km^2 with the absence of detectable signs of human-caused alteration or fragmentation and is based on the Intact Forest Landscape definition of Potapov *et al.* (2008). The degraded primary forest class is a primary forest that has been fragmented or subjected to forest utilisation, e.g., by selective logging or other human disturbances that have led to partial canopy loss and altered forest composition and structure.

Pointing to the descriptions, primary forest of Margono *et al*. (2014) stands for the natural forest, excluding all other tree covers (forest plantation, oil palm and other man-made forests); with term of primary intact forest refers to the primary forest (*hutan primer*) of the MoFor (Table Annex 1.1), and primary degraded forest refers to secondary forest (*hutan sekunder*) of the MoFor (Table Annex 1.1). The primary forest of Margono *et al*. (2014) that equalled primary intact forest plus primary degraded type forests were compared with that of the MoFor, for the years 2000 up to 2012 with three years interval (Figure Annex 1.1). This was performed to assess the primary forest reference mask. The primary forests class of Margono *et al*. (2014) and that of MoFor yielded a 90 percent agreement with an 80 percent Kappa and balanced omission and commission errors (Table Annex 1.6).

Details of the Margono study available at
http://www.nature.com/nclimate/journal/v4/n8/full/nclimate2277.html and the produced data available at
http://glad.geog.umd.edu/indonesia/data2014/index.html.

Table Annex 1.6. Product comparison of Margono et al. (2014) to the data of The Ministry of Forestry of Indonesia for primary forests (intact and degraded forms) for 2000 (starting date) and 2012 (ending date) of the analysis

Assessment for agreement	Primary forest (intact and degraded)	
	2000	2012
Overall agreement	90.7	90.9
Producer's agreement	92.1	90.7

User's agreement	90.1	90.6
Kappa statistic	81.0	81.0

Land cover map of LAPAN

This data is a result of The Land Cover Change Analysis programme (LCCA), the remote sensing monitoring component of Indonesia's National Carbon Accounting System (INCAS). The LCCA provides a wall-to-wall spatially detailed monitoring of Indonesia's forest changes over time using satellite remote sensing imagery. The primary objective of the LCCA is to produce annual forest extent and change products, and initial objective is to map the extent of forested land and the annual changes for the 13-year period from 2000-2012, to provide inputs for carbon accounting activities. The LCCA was conducted in LAPAN and assisted by CSIRO Australia.

Forest is defined as a collection of trees with height greater than 5 metres and having more than 30% canopy cover. For this activity, Landsat 5 (LS-5) and Landsat 7 (LS-7) were chosen as the only feasible data source in providing such monitoring information. Samples derived from high-resolution satellite imagery were use as reference to accurately interpret the land cover classes. Such image resolution could estimate tree density and provides indications of tree height from shadow.

This work has not yet been published in an academic journal, but key activities are outlined in the following paragraph. There are several steps to produce the annual forest extent and change maps of LCCA-LAPAN, including image preparation, forest extent change mapping, as well as review of the product. The outputs from one step is automatically used as the input for the next step. Image preparation is intended to produce a cloud free mosaic. At first, the images in scenes (path/row) are selected and geographically corrected, if necessary, as those scenes should be aligned to each other and to other maps used as reference. Corrections to normalise every pixel value to be more consistent through time are subsequently executed. Contaminating data, such as clouds and shadows, haze, smoke and image noise that obscures the ground cover are masked. The individual selected-corrected images are then consolidated into mosaic tiles, to simplify the following process.

There are three steps taken into consideration to make the annual forest extent and change products. First, ground truth information; expert knowledge and high-resolution images were used to capture relationships between image signals and the forest/not forest cover, to create a forest base for every single year. A semi-automated matching process was subsequently used to 'match' the adjacent years to the base. At last, knowledge of temporal growth patterns in forest and non forest cover types were used in a mathematical model to refine the single date for more reliable change detection. The final step is to review the products, both to collect feedback on accuracy and to understand the strengths and limitations of the particular works. The review will provide suggested strategies to improve the products in the future. Details on methodology are provided in document entitled

"The Remote Sensing Monitoring Programme of Indonesia's National Carbon Accounting System: Methodology and Products". The forest of LCCA-LAPAN was then compared to the MoFor for the year 2000 and 2012 (see Table Annex 1.7 and Figure Annex 1.1).

Table Annex 1.7. Product comparison of the LCCA-LAPAN result (that refer to tree cover) to The Ministry of Forestry of Indonesia data for forest in 2000 (starting date) and 2012 (ending date of analysis)

Assessment for agreement	Tree cover	
	2000	2012
Overall agreement	78.7	78.1
Producer's agreement	75.6	73.6
User's agreement	89.7	88.7
Kappa statistic	56.0	56.0

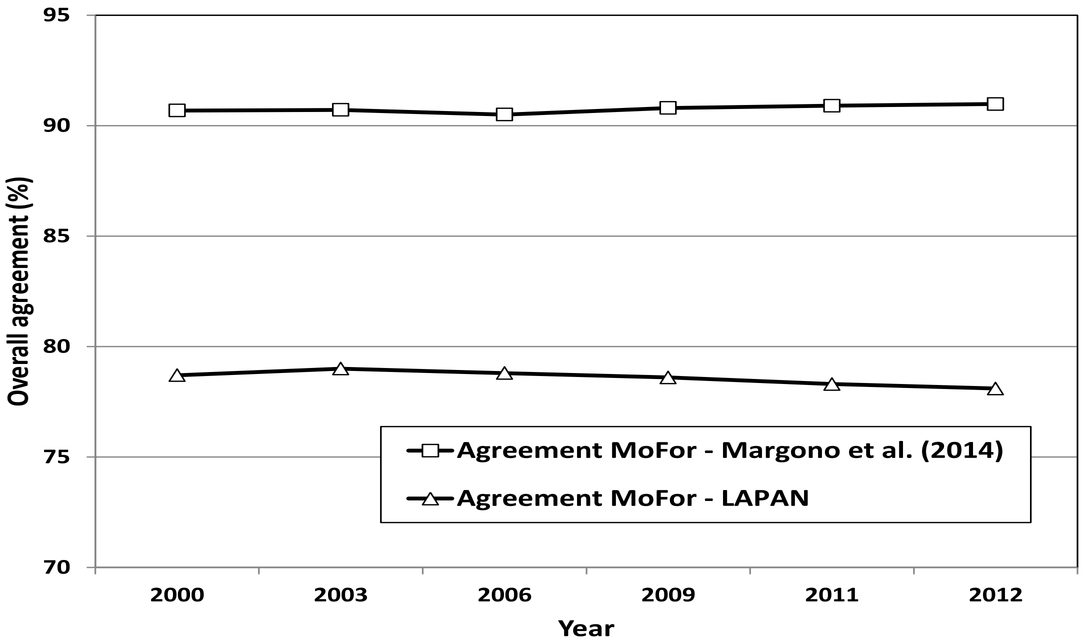


Figure Annex 1.1. Agreement of the MoFor land cover data used in this analysis to the other two independent studies (Margono and LAPAN/LCCA-LAPAN).

Uncertainty analysis of activity data

The procedure for accuracy assessment and uncertainty analysis of activity data has described in the Figure Annex 1.2. In order to measure the REDD+ activities in Indonesia, land cover change classifications were divided into 5 strata, i.e. deforestation, forest degradation, forest gain, stable forest and non stable forest.

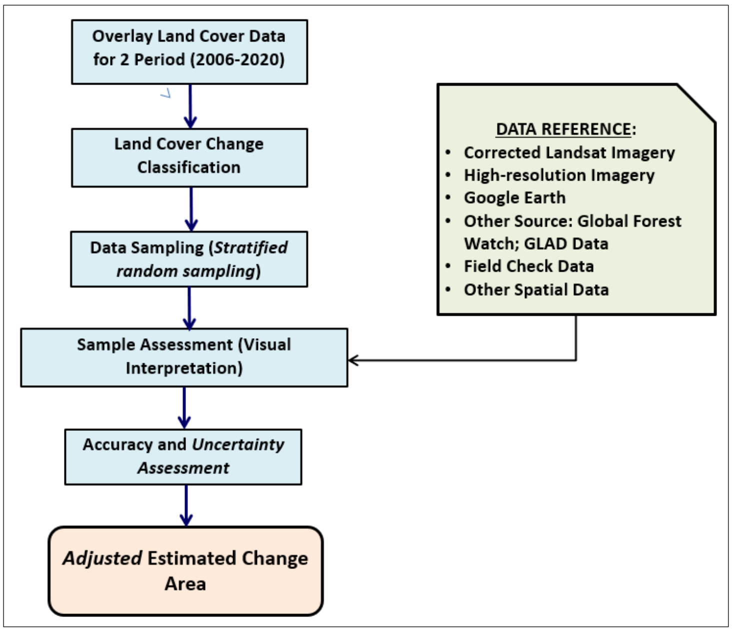


Figure Annex 1.2. Flowchart of accuracy and uncertainty assessment of land cover changes

Land cover change classification could contribute errors to the actual area due to the data source quality, image processing and land cover interpretation process. Therefore, the accuracy assessment and uncertainty analysis of land cover change data should be calculated to understand the accuracy of the maps and to propose area adjustment. Sample-based area estimation approach was applied to estimate uncertainty of land cover change data and the adjusted areas following Olofsson, et al, (2014).

The accuracy assessment and uncertainty analysis was carried out for the forest and land cover change data from the period 2006-2020. The process includes sampling design, sample allocation and distribution, sample assessment, accuracy assessment and uncertainty analysis of land cover change maps (Figure Annex 1.2). A stratified random sampling with the five land cover changes strata was applied to establish the sample size and sample allocation for each stratum. Due to the land cover map using MMU of 6.25 ha, the spatial unit for sample assessment also applies the same area described in the Figure Annex 1.3.

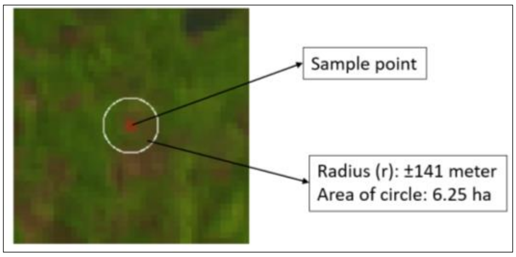


Figure Annex 1.3. Spatial unit of sample assessment

The proportional allocation of the sample was chosen to calculate the sample size for each class, where the sample size was proportional to the relative area for each stratum. However, the strata of forest degradation and forest gain have small areas compared to the others , resulting in sample size for these strata of less than 50 (see column prop allocation 1 in Table Annex 1.8). Olofsson, et al (2014) suggested minimum sample size of 50. The sample size for strata of forest degradation and forest gain can be added from other strata ,the sample unit remaining will be allocated again to strata of deforestation, stable forest, and stable non forest (see column prop allocation 2). Table Annex 1.8 presents the sample size that resulted from the proportional allocation 1 and 2, including the mapped area proportions (Wi), conjectured values of user's accuracies (Ui), and standard deviation (Si).

Table Annex 1.8. Sample size for each strata

Strata (i)	Wi	Ui	Si	Prop Allocation 1	Prop Allocation 2
1 Deforestation	0.0556	0.700	0.458	84	83
2 Forest degradation	0.0233	0.500	0.500	35	50
3 Forest gain	0.0260	0.600	0.490	41	50
4 Stable forest	0.4453	0.900	0.300	676	664
5 Stable non-forest	0.4498	0.700	0.458	682	671
Total	1			1,518	1,518

The sample size from proportional allocation 2 is the initial sample. The sample size can be increased or iterated until the accuracy and uncertainty estimation can not be dropped. The document shows the iterations of sample size for deforestation, forest degradation, and forest gain strata as presented on Table Annex 1.9.

Table Annex 1.9. The sample size after the iteration process

Strata (i)	Wi	Ui	Si	Prop Allocation 2	Sample Size of Iteration
1 Deforestation	0.0556	0.700	0.458	83	332
2 Forest degradation	0.0233	0.500	0.500	50	250
3 Forest gain	0.0260	0.600	0.490	50	250
4 Stable forest	0.4453	0.900	0.300	664	664
5 Stable non-forest	0.4498	0.700	0.458	671	671
Total	1			1,518	2,167

All plot samples were interpreted to estimate the error of the map by comparing the map and reference data presented in the table of error matrix below.

Table Annex 1.10. An error matrix of sample counts

Strata of Land Cover Changes		Deforestation	Forest degradation	Forest gain	Stable forest	Stable non-forest	n Total
Map	Deforestation	199	1	2	35	95	332
	Forest degradation	7	60	-	181	2	250
	Forest gain	7	2	37	144	60	250
	Stable forest	5	14	2	631	12	664
	Stable non-forest	9	-	-	24	638	671
	Total	**227**	**77**	**41**	**1,015**	**807**	**2,167**

Results of an error matrix of sample and map area proportion were calculated to estimate the SE estimated variance, 95%CI, and Coefficient of Variance (CV), then followed by estimation the adjusted area of land cover change strata. Using the sample-based area estimation approach allows to estimate the accuracy and uncertainty of land cover changes as presented in the table below.

Table Annex 1.11. Result of accuracy assessment and uncertainty analysis

	Deforestation	Forest degradation	Forest gain	Stable forest	Stable non-forest
SE estimated variance	0.002933273	0.002573271	0.00114	0.005149801	0.004673982
95% CI (1.96)	0.005749215	0.005043611	0.002231470	0.010093611	0.009161004
Original Map areas	10,576,625	4,437,106	4,947,353	84,778,001	85,626,244
Adjusted area est (ha)	8,389,246	2,923,830	1,051,278.209	90,804,420	87,196,555
95% CI	1,094,451	960,129	424,794	1,921,474	1,743,938
CV	0.067	0.168	0.206	0.011	0.010
User accuracy	0.599	0.240	0.148	0.950	0.951
Producer accuracy	0.756	0.364	0.696	0.887	0.934
Overall accuracy	0.894				
Percent of Area	5.56	2.33	2.60	44.53	44.98

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Annex 2. Peat land data

Peatland mapping activities in Indonesia are closely related to soil mapping projects for agricultural development programs, conducted by the Ministry of Agriculture. Indonesia has developed a procedure for peatland mapping based on remote sensing at a scale of 1:50.000 (SNI 7925:2013). Indonesia's peat land map has been updated and released several times due to the dynamics of data availability.

For this FRL submission, the peat map used is the peatland map revised in 2019 at a scale of 1:50.000 from Balai Besar Litbang Sumberdaya Lahan Pertanian (BBSDLP) Ministry of Agriculture.

This map was generated based on multi-source satellite images to delineate soil mapping units combined with soil maps 1:50.000 and peatland maps 1:250.000, and subsequently verified with rigorous ground truthing. Field transects were made between rivers using systematic distances to observe peat morphological features and thickness resulting in 18,232 data points that included 14,185 new observations and 4,047 legacy points (Anda et al. 2021).

The data method to update Indonesia's peat map is as follows:

Data Input:

- Sattelites images (Landsat ETM-7, Landsat 8 OLI, ALOS, SPOT-5 and SPOT-6/7, and DEM/SRTM)
- Soil maps/legacy data from Ministry of Agriculture.
    - Soil maps 1:250.000 (BBSLDP, 2014)
    - Peatland maps 1:250.000 (BBSLDP, 2011)
    - Semi detailed soil maps at 1:50.000 (BBSLDP, 2019)
- Secondary maps of peatland distribution
    - Peatland maps in Sumatera 1990-2002 (Wahyunto et al., 2003)
    - Peatland maps in Kalimantan 2000-2002 (Wahyunto et al., 2003)
    - Peatland maps in Papua 2000-2001 (Wahyunto et al., 2003)
- Rupabumi Indonesia (RBI) maps with scales of 1:25.000 - 1:50.000 from Geospatial Information Agency.
- Geological maps from The Ministry of Energy and Mineral Resources.

Method:

A comparative method was used. All data collected from any sources were compared spatially using spatial data analysis tools and combined with a literature review. In order to increase the accuracy of the results of the comparative method, validation was conducted by ground truth surveys. The soil classification system used in this map refers to Presidential Instruction (Inpres) No. 10/2011 (forest moratorium) and the Minister of Agriculture Regulation (Permentan) No. 4/2009.

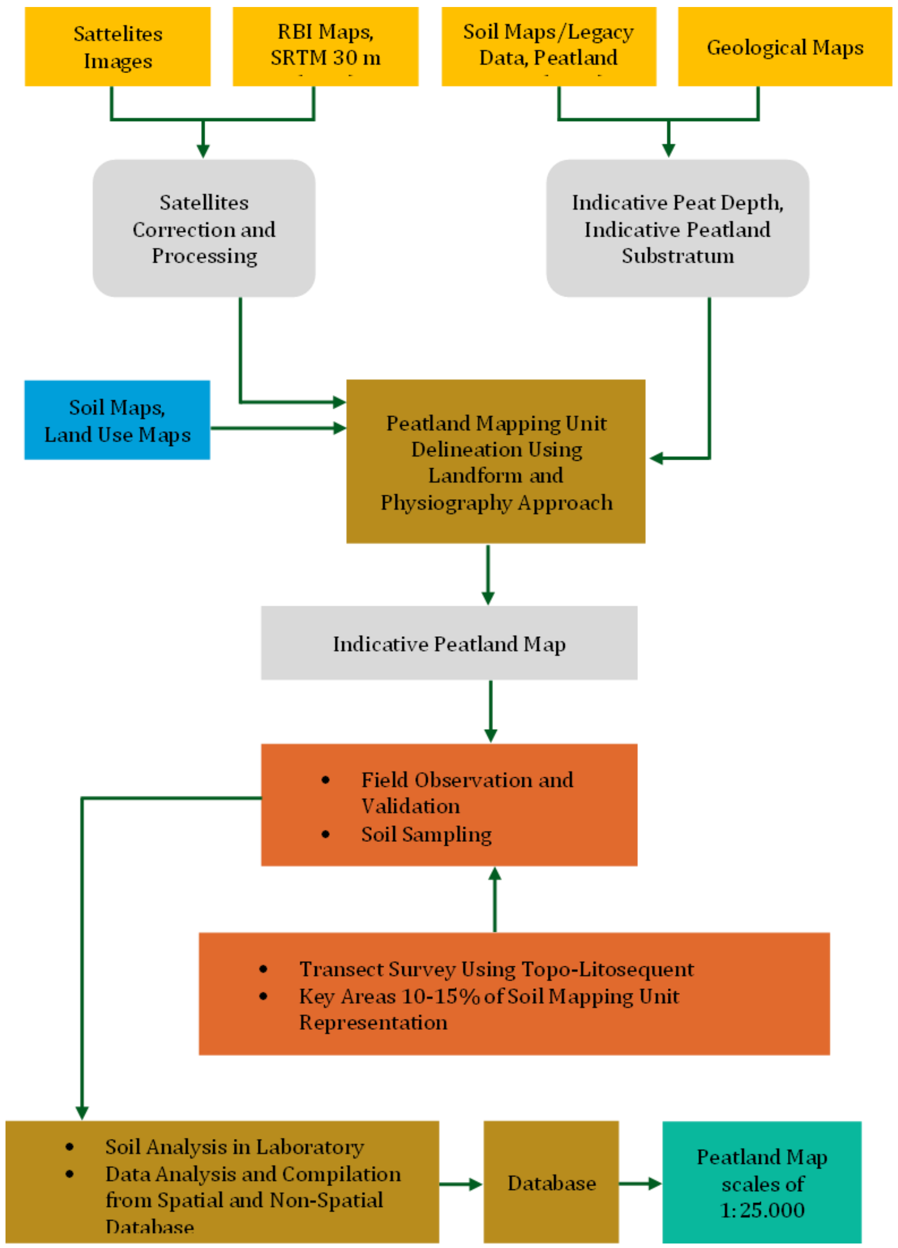

Figure Annex 2.1. Flow chart of peat land mapping procedure

A combination of remote sensing techniques and physiography/landform analysis (supported by topography and geology data) were used to increase the accuracy. Remote sensing indicators used for detecting peatland area: wetness (surface drainage), topography, and land cover. Field measurements were conducted to verify the remote sensing analysis results. The level of error of using this method to produce peat land map was 20-30%. The reliability of the map depends on the following factors:

- The density of sample points in ground truth activity
- The variety of soil types
- The quality of the remotely sensed data
- The accuracy of the map soil delineation and land unit map.
- The competency of the surveyors.

The present extent of peatland in Indonesia (13.43 million ha) (BBSLDP, 2019) was smaller than the previous map (14.91 million ha). The smaller peatland extent in the current semi-detailed mapping inventory than the previous estimate in 2011. Differences in peatland area attributed to different map scales were systematically shown by comparing the peatland maps of coarse reconnaissance scale (1:250 000) (BBSDLP, 2011) and the present semi-detailed scale (1:50 000) (BBSDLP, 2019) may result primary from (Anda et al. 2021):

- Segregation of mineral soil inclusions previously considered as peatland
- Improved remote sensing and GIS tools (e.g., DEM/SRTM) that prevented misclassification of peatland areas
- Extensive field observation for verification of peatland boundaries and thickness requirements (≥50 cm) that eliminated peatlands lost to enhanced decomposition from agricultural management and drainage practices

Tabel Annex 2.1. The comparison of previous and revised peatland maps

Island	Peatland Map 1:250.000 (BBSDLP, 2011)	Peatland Map 1:50.000 (BBSDLP, 2019)
Sumatera	6,436,649	5,850,561
Kalimantan	4,778,004	4,543,362
Papua	3,690,921	3,011,811
Total	14,905,574	13,405,734

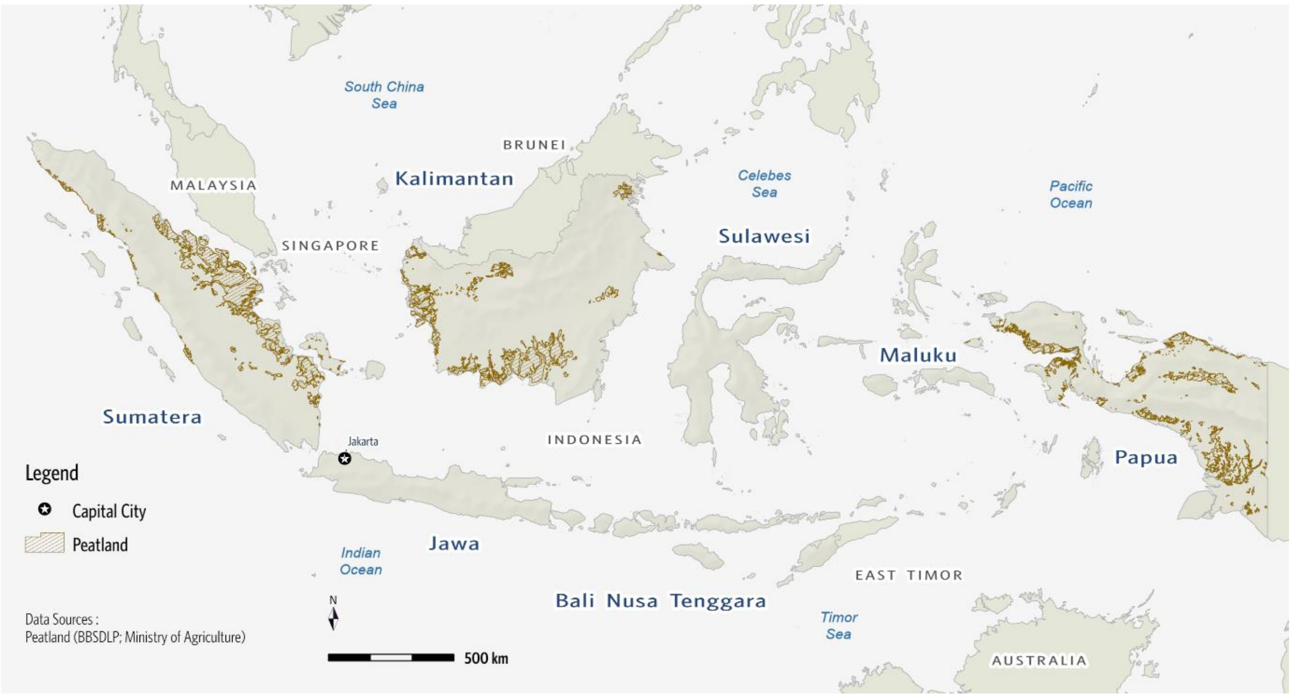

Figure Annex 2.2. Peatland distibution from the revised peat map (BBSLDP, 2019)

Reference

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Annex 3. Burn area mapping

In the past four decades, vegetation fires have become recurrent events in the tropical ecosystem including Indonesia (Dennis *et al*, 2001; Nepstad *et al*, 1999). Prolonged dry seasons boosted by El Nino increase the risk and intensity of fires, particularly in drained peatlands. From1982-1983, fires affected approximately 5 million hectares of forests in Borneo (Leighton and Wirawan, 1986). From 1997-1998, large-scale fires raged tropical Southeast Asia and Central America. In Southeast Asia, fires burned mostly in Indonesia, affecting some 9.5 million hectares of forest and land (Bappenas-ADB, 1999). The most recent fires hit Indonesia during the extreme dry seasons in 2015 and 2019. More than 2 million hectares of forest and land were burned during 2015 (KLHK, 2021).

As a major source of emissions, accurate estimation of burn areas is crucial for assessing the national GHG emission level. A robust and standardized method is required to produce burn area maps annually. MoEF has mapped the burn areas based on remote sensing data from 2000 until 2020 (KLHK, 2021). During that period, the largest burn areas occurred in 2006 and 2015, *i.e.,* 3.9 million hectares and 2.6 million hectares, respectively (Figure Annex 3.1). Most fires occurred in mineral soils, only about 30% in peatlands. However, most of fires occurred in non forest land cover types, between 2% - 13% were in forest cover types (Figure Annex 3.2). Fires occuring in forest estates were slightly larger than in non forest estates or other land use.

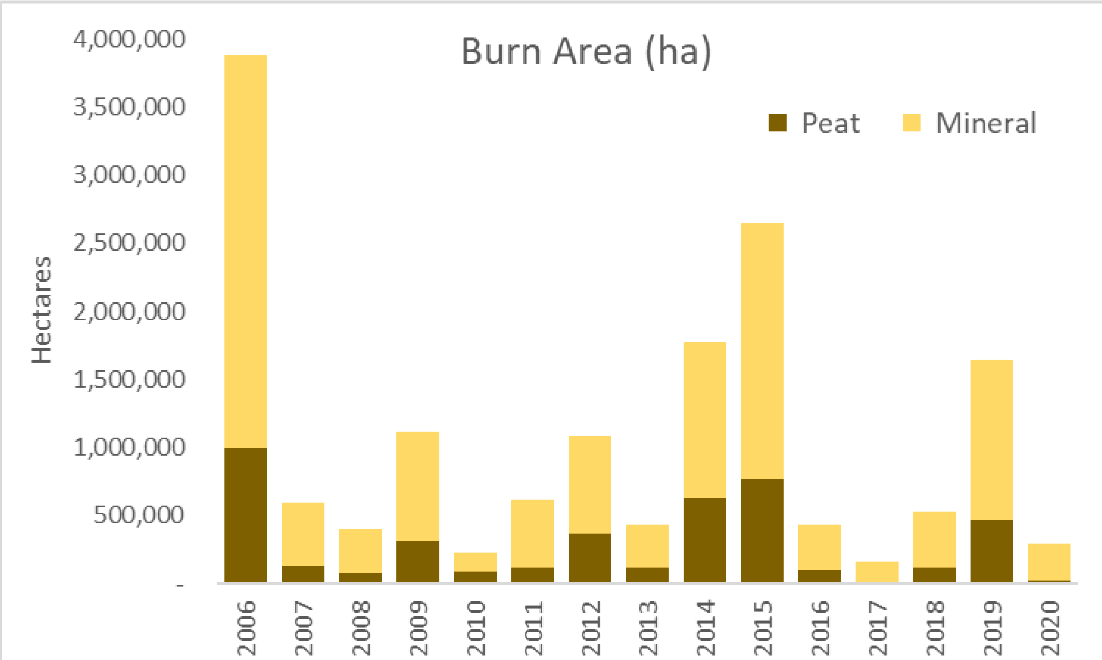


Figure Annex 3.1. Estimates of burnt areas from peatland and mineral soils 2006-2020 (KLHK, 2021)

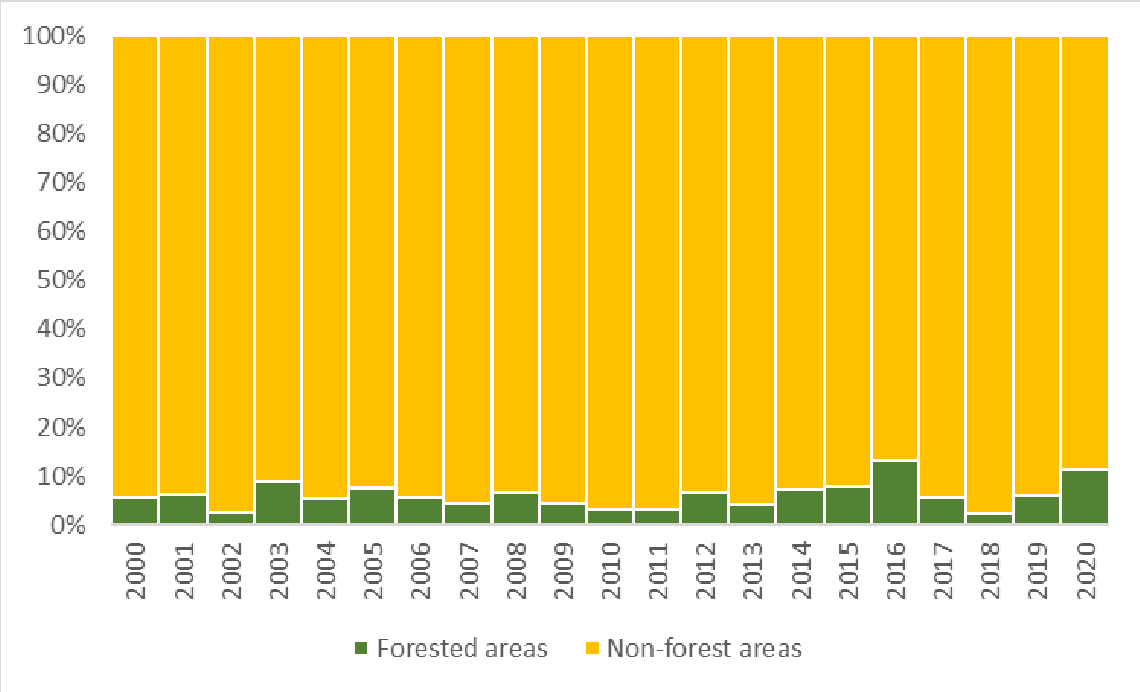
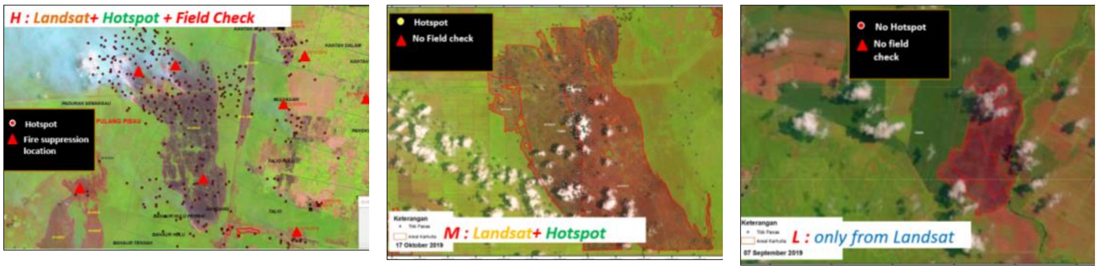


Figure Annex 3.2. Proportion of birned areas in peatland and mineral soils 2006-2020 (KLHK, 2021)

The classification method for identifying burn areas was based on visual interpretation of medium resolution imageries, i.e., Landsat 5/7/8 with 30 m resolution and Sentinel 2A and 2B with 20 m resolution. In addition, several additional datasets were used to support and validate the burn scars, including MODIS and NOAA hotspot, groundthruthing data and burn area model based on normalized burn ratio (NBR).

Visual interpretation of the satellite imageries was performed on a map scale of 1:25,000 – 1:50,000 to obtain a reasonable resolution of published maps at a scale 1:50,000 to 1:250,000. The minimum burn area polygon to be identified was 0.5 cm x 0.25 cm at map scale of 1:50,000, which is equivalent to a minimum area of 6.25 hectares. Classification of burn scar area refers to SOP of Forest and Land Fire Assessment that can be accessed via https://opsroom-sipongi.menlhk.go.id/storage/files/537383_1647404256.pdf. The burnt area can be detected from medium resolution imagery, such as Landsat 8, using the visual interpretation method, based on the colour (red, brown, or black), tone (dark) from the RGB combination of SWIR-1, Near Infrared, Red, pattern, site and association. Either hotspot or field check data were used for burn scar validation. Based on the data and objects that can be detected from remote sensing data, the burn scar area can be classified into three levels of accuracy as below. The classification of each burn area polygon will include the delineation of the polygon with three levels of accuracy, *i.e.,* high, medium and low, as presented at Figure Annex 3.3. High level accuracy, if within the polygon, satellite imageries, hotspot data and ground thruthing data confirm that fire occurs in the polygon. While medium level accuracy if only hotspot and burn scars in satellite imageries are detected. When fire is detected only in satellite imageries, the polygon will be considered low level accuracy.



(a) High accuracy level

(b) Medium accuracy level

(c) Low accuracy level

Figure Annex 3.3. The classification of accuracy level for burn scar area

Of the three-accuracy level, only high and medium levels were applied for activity data of burnt area. Data observed in low level will be excluded unless there is other supporting evidence such as ground checking of fire events, then the areas will be included in the analysis. Table Annex 3.1 presents the example of the proportion level of accuracy for 2020 and 2021, where almost 50% of the low level was categorized to burn scar activity data after the observation. The procedure for estimating peat burnt area is presented below (Figure Annex 3.4).

Table Annex 3.1. Area proportion based on the accuracy level for year 2020 and 2021

Level of Accuracy	Year 2020		Year 2021	
	Area (Ha)	% of Area	Area (Ha)	% of Area
H	15.689	4%	25.724	6%
M	281.253	75%	333.140	75%
L	80.154	21%	83.072	19%
Total	377.096	100%	441.936	100%

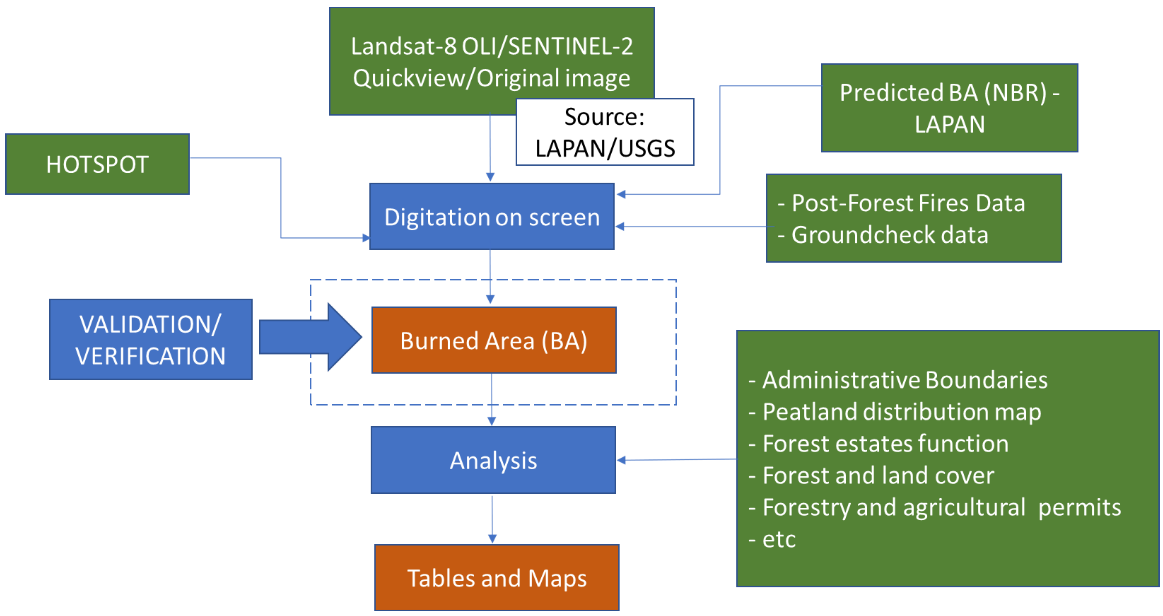


Figure Annex 3.4. Procedure for estimating peat burnt (KLHK, 2021)

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Annex 4. Forest and land carbon stock data

National Forest Inventory

NFI was initially a World Bank and United Nations supported project to assist MoFor in conducting forest resource enumeration from 1989 to 1996. The implementation was carried out through technical assistance from FAO. The goal of the NFI project was to support the development of a forest resource information system and institution, including to establish a Forest Resource Assessment (FRA). The implementing agency of the NFI project was the Directorate General of Forest Planning or DG of Planology (DGFP) of the Ministry of Forestry.

NFI was designed to encompass all components related to forest inventory at a national scale. This includes Field Data System (FDS), Digital Image Analysis (DIAS), Geographic Information System (GIS) and National Forest Inventory Information Service (NFIIS). Through this project, several forest inventories plots, both permanent (PSPs) and temporary sample plots (TSPs), have been established and measured throughout the country. The plots are distributed with systematic sampling throughout the country on a 20 km x 20 km grid. All plots were distributed in lowland areas below 1000 m above sea level. In addition to that, a land and forest cover map was produced at a scale of 1:250.000 based on satellite images covering the national area.

In 1996, the NFI project published the first statistic report on Indonesian forest resources. This is the first and complete report made available by the Indonesian Government describing complete and detailed information on forest resources, forest and land cover and timber stocks from each forest function in Indonesia, except Java. Up to now, the NFI system has been implemented as part of the regular program from the DGFP. Activities related to NFI that DGFP is implementing include re-enumeration or re-measurement of the established PSPs that still exist, establishing new PSP/TSP in new areas for filling the gaps and additional plots in mountainous region and conservation areas.

NFI sampling design

The purpose of the plots established by the NFI project was to conduct FRA at the national scale. The NFI plots are a group of nine square plots (1 PSP and 8 TSPs), or so called a cluster. The plot size is 100 m x 100 m and systematically placed in 3 x 3 sub plot/tract with 500 m distance between sub plots. The sub-plot/tract in the middle (no 5) is measured as PSP and TSP. The other eight tracts are TSP. PSP is divided into 16 recording unit (RU) areas (25 m x 25 m).

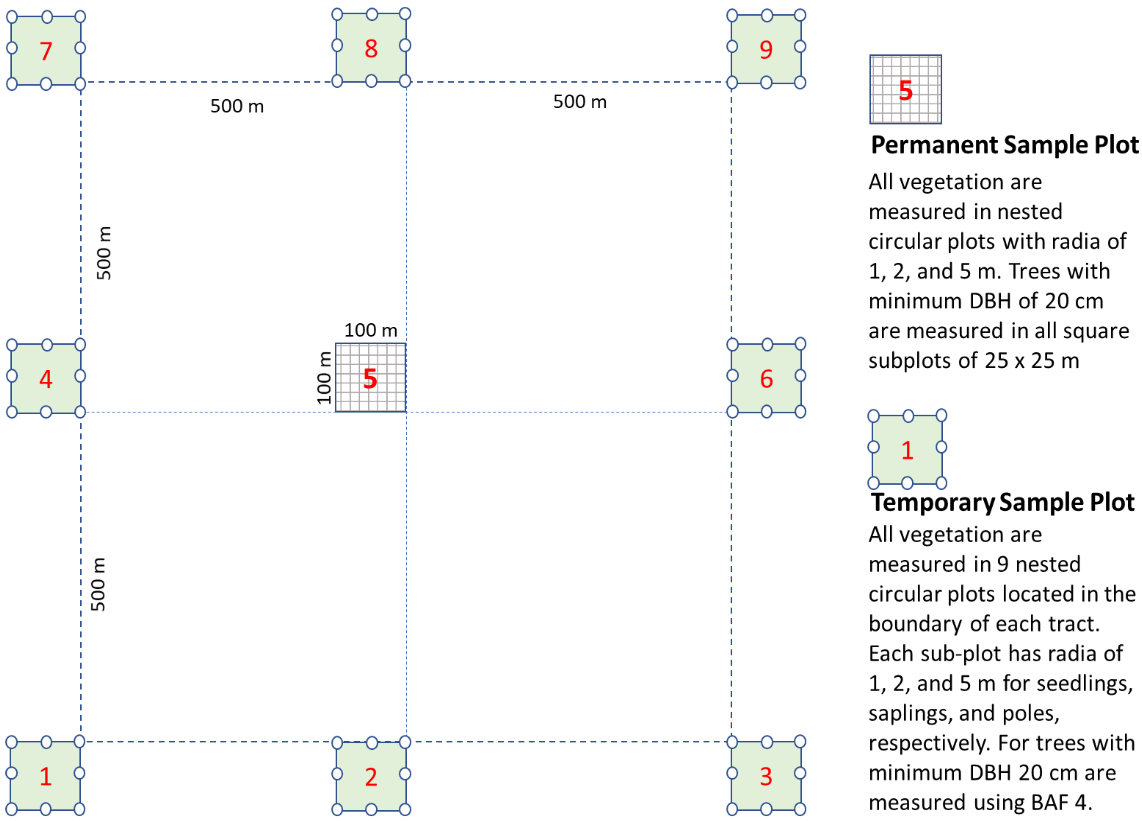


Figure Annex 4.1. Cluster sampling of NFI plots

NFI Cluster distribution

NFI clusters were systematically distributed at 20 km x 20 km covering all land cover types within the forest area of Indonesia (see Figure Annex 3.2). Most of the clusters are located in the area with altitudes below 1000 m above sea level (ASL). Along with the improvement, several clusters of PSPs were established between the 20 km x 20 km grid (i.e. become 10 km x 10 km) in production forests and at an altitude above 1000 m ASL. None of the clusters are located outside forestland, even though it is forested.

Since the commencement of the NFI program in 1989, PSP/TSP have been established and measured until 2019 totaling 4,067 clusters distributed in seven major islands/regions, out of which 3,423 clusters are located in natural forest classes. Sumatra and Kalimantan have the largest plot allocation, with 23.5% and 32.5%, respectively. Some clusters are no longer maintained due to conversion into other land use.

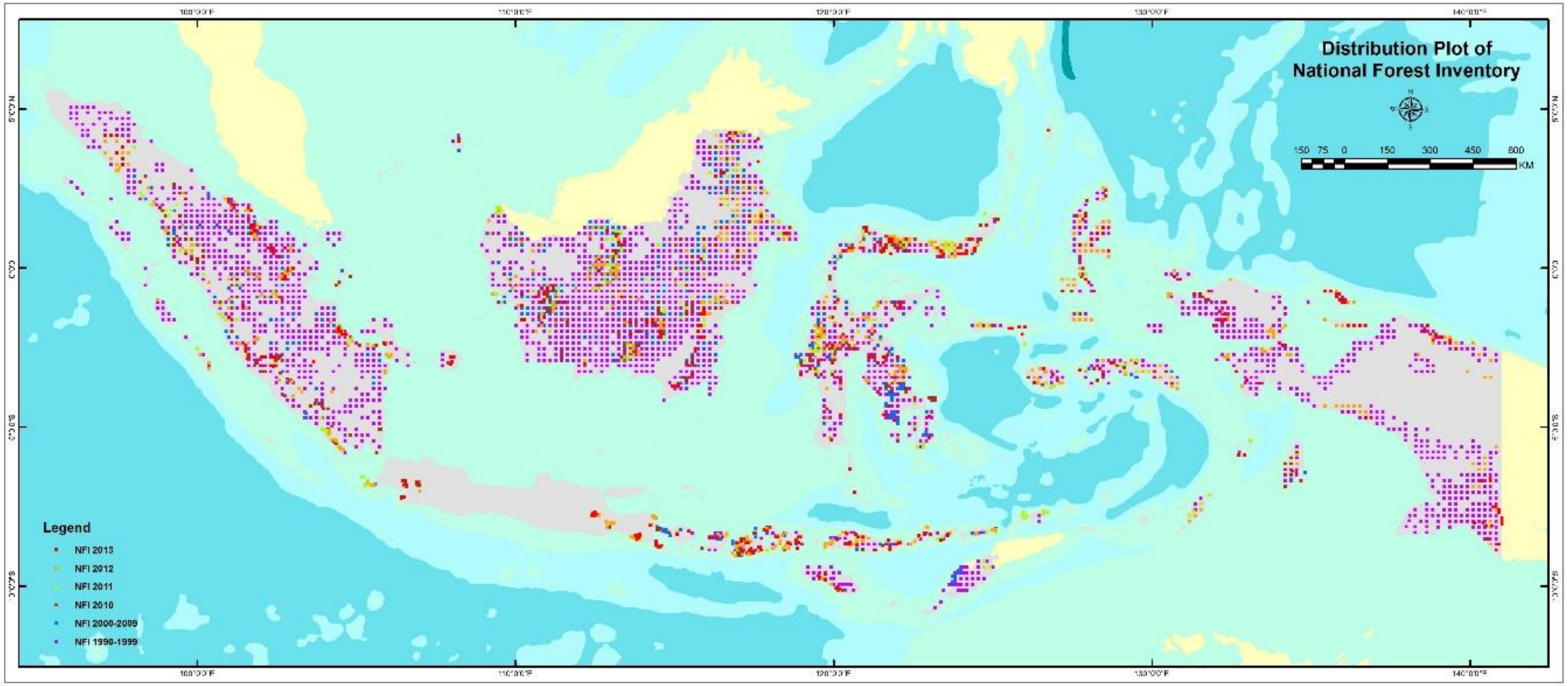


Figure Annex 4.2. NFI's PSP/TSP distribution map.

Table Annex 4.1. Cluster distribution of NFI's PSP/TSP in natural forest classes

Islands	N Clusters	%
Java	103	3.01
Kalimantan	1096	32.02
Maluku	173	5.05
Bali Nusa Tenggara	238	6.95
Papua	489	14.29
Sulawesi	514	15.02
Sumatra	810	23.66
Total	3423	100.0

Parameter being measured

Since the primary purpose of NFI was to monitor forest resources, data to generate timber volume or stocks were strongly required. These include species name (local name), tree DBH or above buttress, tree height, bole height, and buttress height. The quality of the trees was also recorded for both stem and crown quality. Within the plots, bamboo, rattan, and other palms were also measured in addition to trees. At the cluster level, general information such as, ecosystem type, forest type, land system, altitude, aspect, slope, terrain, and logging history were also recorded. All trees are measured in subplots according to the size class:

- Subplot circle with radius = 1 m for measuring seedlings (height less than 1.5 m).
- Subplot circle with radius = 2 m for measuring saplings (dbh less than 5 cm and height from 1.5 m or more).
- Subplot circle with radius = 5 m for measuring poles (dbh between 5 cm – 19.9 cm).
- For PSP, all trees inside the recording unit with DBH = 20 cm or more are measured. While for TSP, use BAF = 4 for basal area and volume estimation.

Post stratification

For the FRL calculation, the land cover categories for each plot were allocated from the land cover map based on the NFI data that was measured. The information in this post-stratification is more relevant if FREL is needed, since the land use types and forest types recorded in the NFI data were different or not adjusted to the current land cover categories used for the FREL.

NFI data calculation

Only PSPs data were used for the calculation (Tract No. 5). Furthermore, only natural forest classes were included. In total, 3,423 PSP measurements (1990-2019) nationwide in natural forest classes were available for data processing and analysis. Some PSPs have been remeasured and some new ones have been established and measured after 2013, where the data from previous measurements were used for FREL submission in 2015. In this version, we combined data from the last measurement of PSPs from the previous period (1990-2013) and new measurements conducted from 2014 onward including measurement data from the mangrove ecosystem.

All the trees in the plot and the plot information were examined to ensure accurate information as part of the quality assurance process. Data validation included: (a) Verification of plot location overlaid with the MoFor land cover map, (b) verify the number of registration units (sub plots) in each plot, (c) verify measurement data by filtering DBH anomalies and species names of individual trees in the plots, (d) verify the information about the basal area, stand density, etc.

Using the total number of PSPs measured, the data validation process reduced the useable number of measurement data to 3,035 for further analysis. These selected PSPs were primarilly located in drylands and swamp forests. However, there are 71 PSPs located in the mangrove forest. In addition, TSP data of Mangrove forests that were also measured by NFI system

Inclusion of TSP – NFI Data in the calculation of carbon stock

In addition to PSP data, NFI system also provides TSP data, which were collected using the point sampling method, based on basal area factor 4 (BAF 4). Therefore, the analysis differs from the PSP data, in particular for the AGB estimate. The main purpose of the sampling point is to estimate the basal area of the plots without measuring the diameter of each tree. Instead, we estimate the AGB based on the calculated basal area of each plot. For this purpose, the relationship between the basal area of the plots and the AGB of the plots was developed (see Figure Annex 4.2).

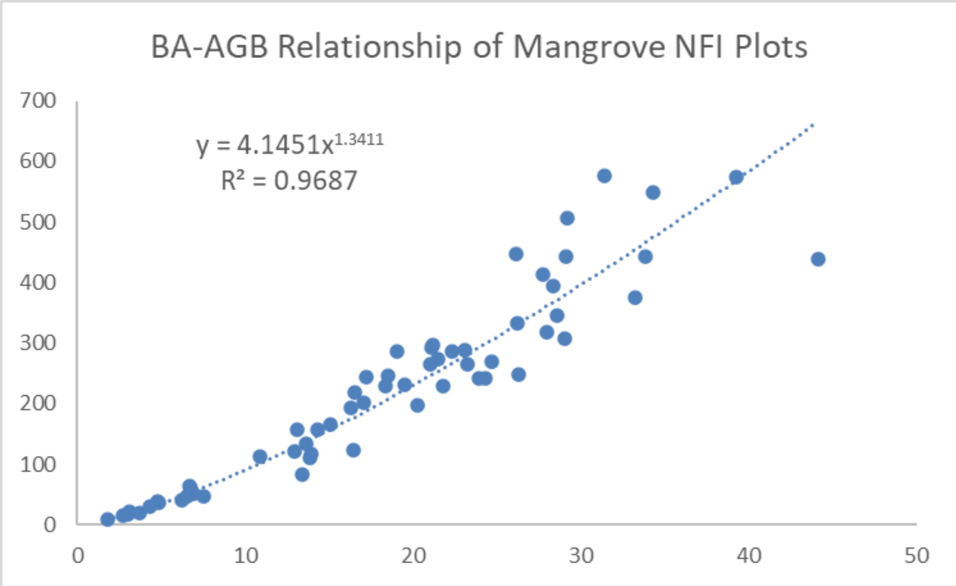


Figure Annex 4.2. Scatter plot relationship between basal area and aboveground biomass based on mangrove NFI plot

Selection of Unbiased Allometric Equations

an allometric equation was applied using field measurement data (DBH and tree species to estimate the total tree biomass,). The 1st FREL used the allometric equations of Chave *et al.* (2005) for all forest types. The equation was further improved by Chave *et al.* (2014) using additional data from pan tropical forests, suggesting that environmental stress factor (E) was a significant factor in AGB estimation. In addition, other Tier-2 allometric equations were developed specifically for Indonesia, e.g. for peat swamp forests (Manuri *et al.*, 2014), dipterocarp forest (Manuri *et al.*, 2016), lowland forest (Manuri *et al.*, 2017) and mangrove forest (Komiyama, Ong and Poungparn, 2008, and Kusmana *et al.*, 2018).The use of locally developed equations will provide a more accurate and non-biased estimate, than global equations. Therefore, in this submission, the AGB of individual trees in the plots wase estimated using an allometric model developed for Indonesian forests (Manuri *et al.*, 2017), which used DBH, wood density (G) of the species and region as the key parameters.

We compared some equations applied to NFI data to assess the mangrove biomass. These include Komiyama *et al*, 2005 and Chave *et al* 2005, which are specific for mangrove forests. It is suggested that the AGB prediction using Komiyama *et al.*, 2005, Chave et al.,2014 and Manuri et al,, 2017 are similar to each other, but Chave et al., 2005 is different (see Figure Annex 4.3).

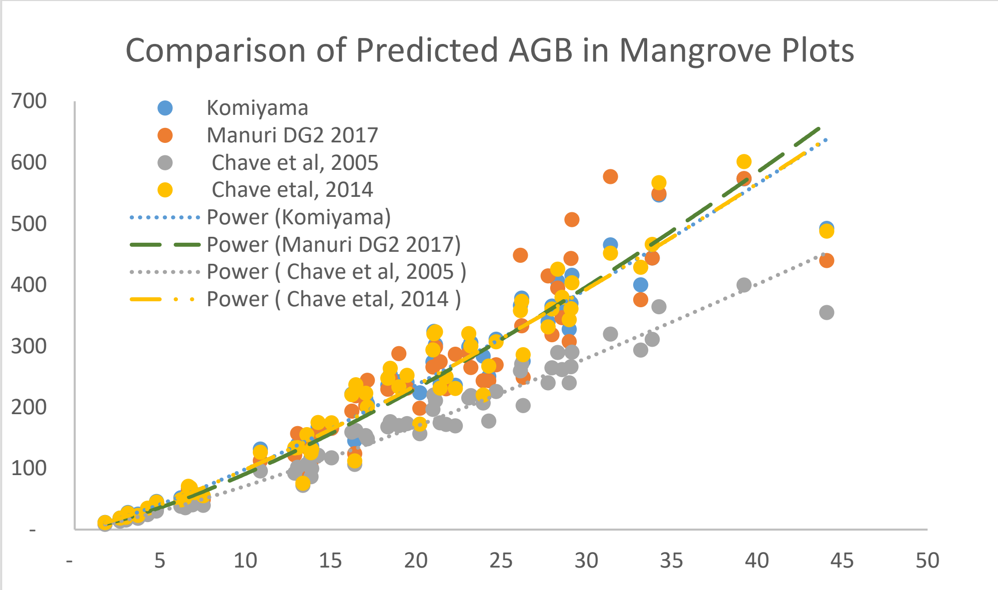


Figure Annex 4.3. Comparison of allometric equations applied to mangrove plots of NFI data

To further analyze for selection of the best allometric for mangrove forests, we used independent data of unpublished destructive sampling from mangrove forests in South Sumatra. The total number of samples is eight trees from various species, including *Rizhopora apiculata*, *Bruguera gymnorhiza*, and *Xylocarpus granatum*, with DBH from 16 cm to 58 cm.

We converted the destructive sampling AGB data and predicted AGB data into log natural and compared using scatter plots and linear regressions. We found that Chave et al. 2005 is better explained the variation of the observed AGB in mangrove forests, with higher adjusted R^2, intercept close to zero and slope close to one. Therefore, we suggested using mangrove allometric equation for estimating AGB in mangrove plots.

Table Annex 4.2. regression sttaistics of the comparison between predicted AGB and destructive sampling data (n = 8)

	Regression Statistics		Intercepts			Slope		
Equations	***Adj R2***	***SE***	***Mean***	***SE***	***Departure from 0***	***Mean***	***SE***	***Departure from 1***
Komiyama etal, 2005	0.978	0.195	-0.839	0.397	0.839	1.100	0.062	0.100
Chave etal, 2005	0.985	0.162	0.060	0.288	0.060	0.980	0.045	0.020
Chave etal, 2014	0.978	0.196	-0.871	0.402	0.871	1.094	0.062	0.094
Manuri etal, 2017	0.978	0.197	-0.544	0.386	0.544	1.059	0.060	0.059

Table Annex 4.3. Allometric equation used in FRL

Forest Type	Reference	Allometric Equations using D and ρ variables
Mangrove Forest	Chave et al, 2005	$AGB = Exp\ [-1.349 + 1.98\ Ln\ D + 0.207\ (Ln\ D)^3 - 0.0281\ (Ln\ D)^3] \times \rho$
Other forest	Manuri *et al.*, 2017	<u>Sumatera - Kalimantan:</u> $AGB=0,167D^{2,560}G^{0,889}$ <u>Jawa – Bali – Nusa Tenggara – Sulawesi – Maluku:</u> $AGB=0,151D^{2,560}G^{0,889}$ <u>Papua:</u> $AGB=0,206D^{2,560}G^{0,889}$

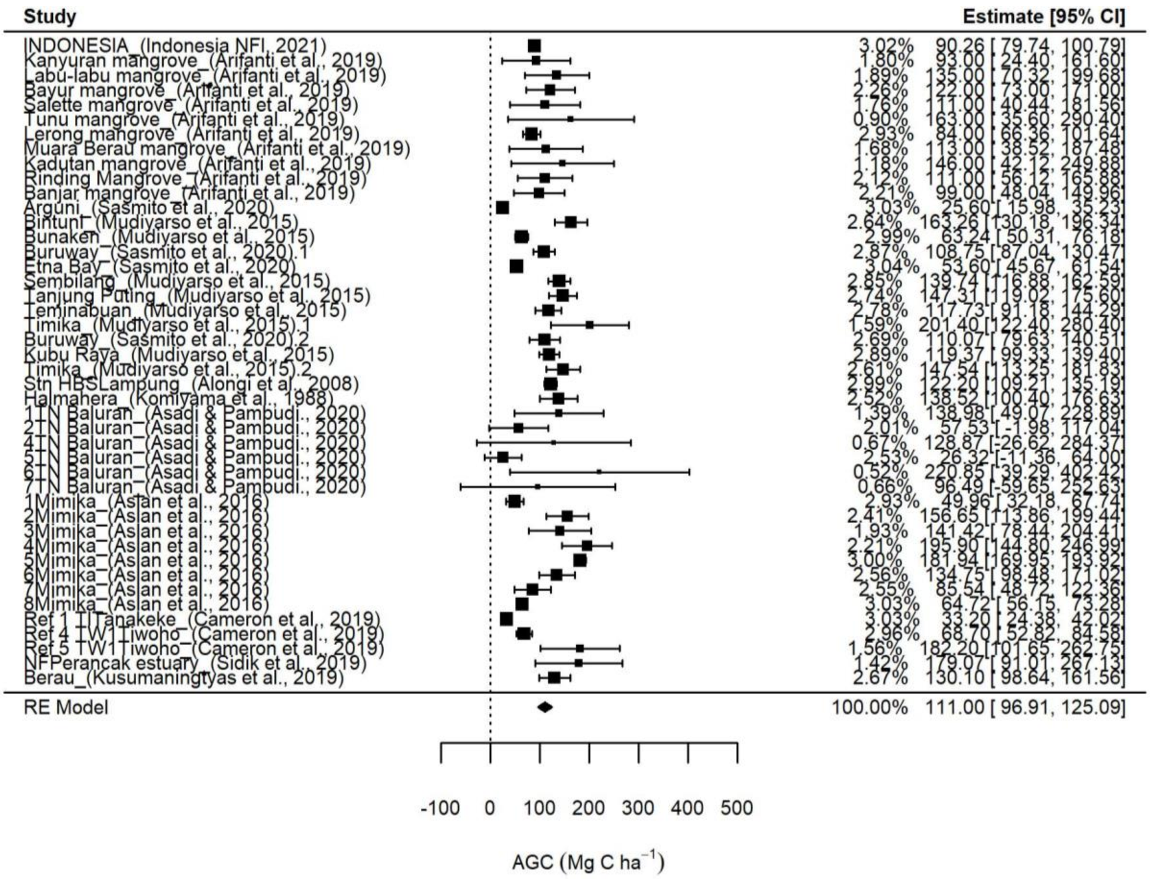
The G values were derived from the database of the MoEF through the Research, Development and Innovation Agency/FORDA (Krisnawati etal, 2012), which is a compendium of G data for Indonesian tree species compiled from various sources (e.g. Hanum and Maesen, 1997; Oey, 1951; Lemmens and Wulijarni-Soetjipto, 1992; Lemmens *et al.*, 1995; Soerinegara and Lemmens, 1994; Sosef *et al.*, 1995; Suzuki, 1999; Verheij and Coronel, 1992). The database provides information on WD by species, genus, and family.

Table Annex 4.4. The Estimates of AGB stocks in Dryland and Swamp Forest in Indonesia (by Main Island)

Main Island	Forest Type	Mean AGB (t.d.m ha^{-1})	95% Confidence Interval (t.d.m ha^{-1})		N of plot measure ments
Bali Nusa Tenggara	Primary dryland	278.50	255.30	301.69	99
	Secondary dryland	133.61	119.58	147.63	123
	Primary swamp				
	Secondary swamp				
Java	Primary dryland	345.46	227.04	463.88	9
	Secondary dryland	202.04	175.69	228.39	86
	Primary swamp				
	Secondary swamp				
Kalimantan	Primary dryland	323.63	303.83	343.44	210
	Secondary dryland	214.69	205.89	223.48	607
	Primary swamp	249.92	193.34	306.50	8
	Secondary swamp	187.05	172.60	201.51	179
Maluku	Primary dryland	236.20	195.91	276.49	17
	Secondary dryland	162.59	145.88	179.30	104
	Primary swamp				
	Secondary swamp				

Main Island	Forest Type	Mean AGB (t.d.m ha^{-1})	95% Confidence Interval (t.d.m ha^{-1})		N of plot measure ments
Papua	Primary dryland	266.70	248.70	284.69	180
	Secondary dryland	216.48	194.73	238.22	126
	Primary swamp	195.37	167.58	223.16	73
	Secondary swamp	121.29	93.27	149.31	36
Sulawesi	Primary dryland	246.55	231.90	261.21	243
	Secondary dryland	159.99	149.24	170.74	234
	Primary swamp				
	Secondary swamp	139.48			1
Sumatra	Primary dryland	338.35	318.27	358.43	176
	Secondary dryland	213.28	201.08	225.48	351
	Primary swamp	311.75	234.65	388.86	15
	Secondary swamp	179.55	165.12	193.98	158

Study Primary Mangrove Forest in Indonesia



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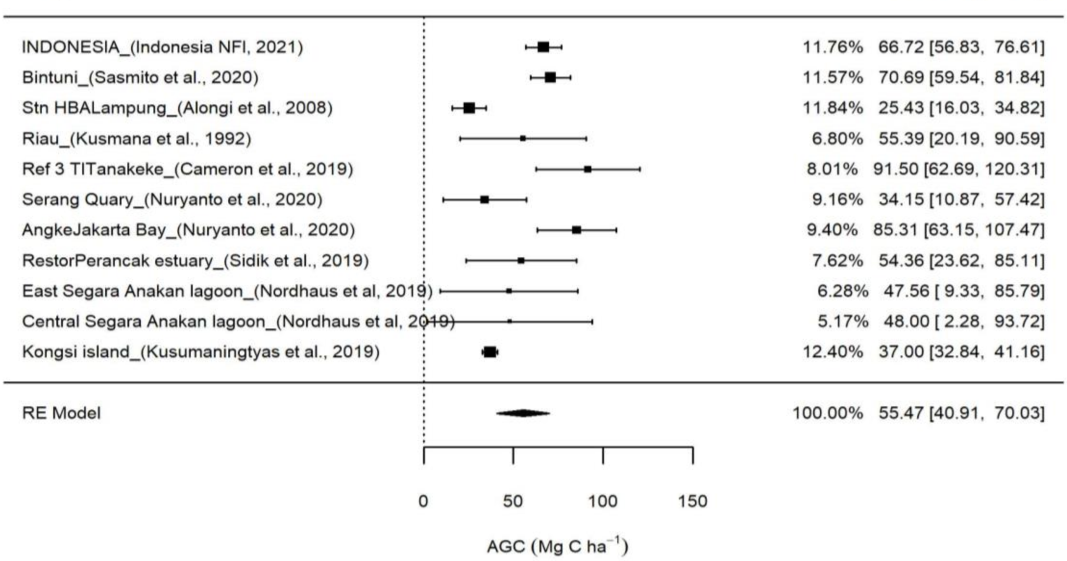
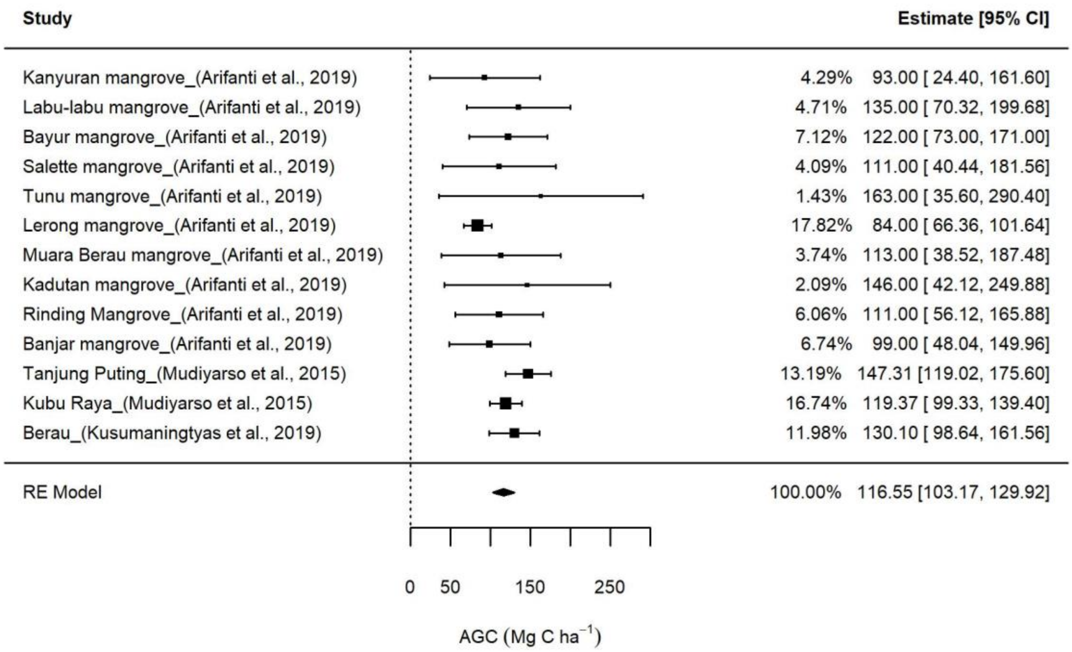


Study Primary Mangrove Forest in Kalimantan



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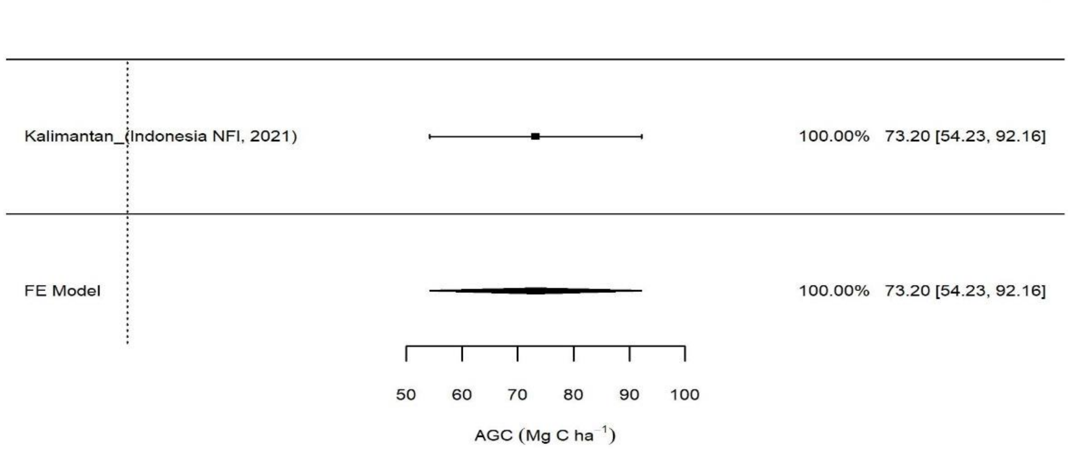

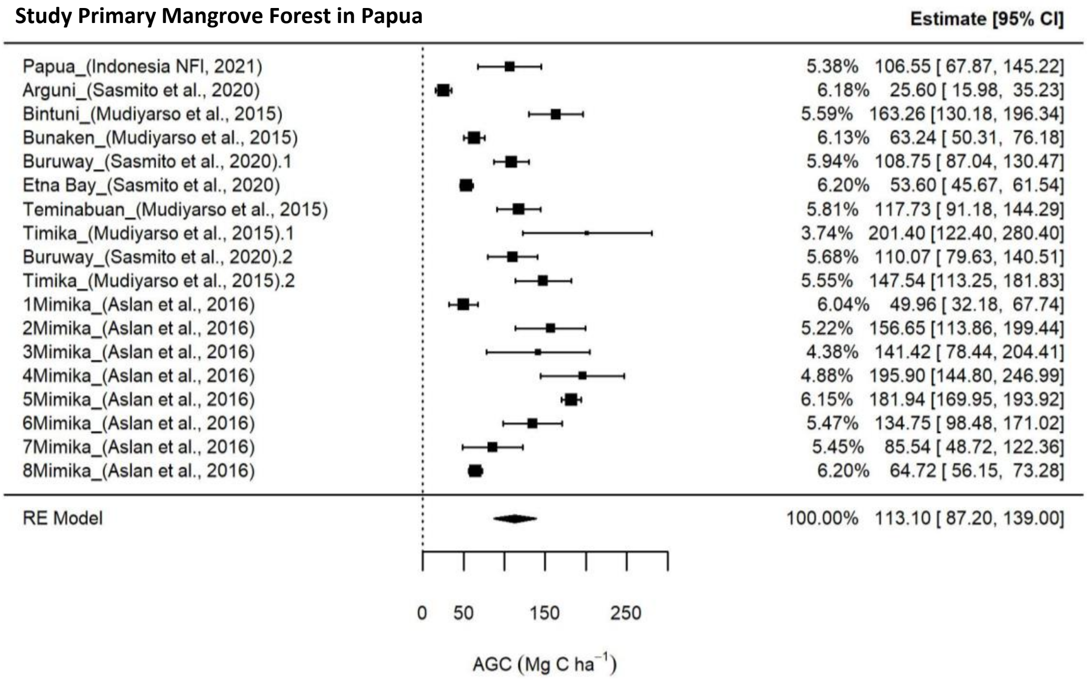

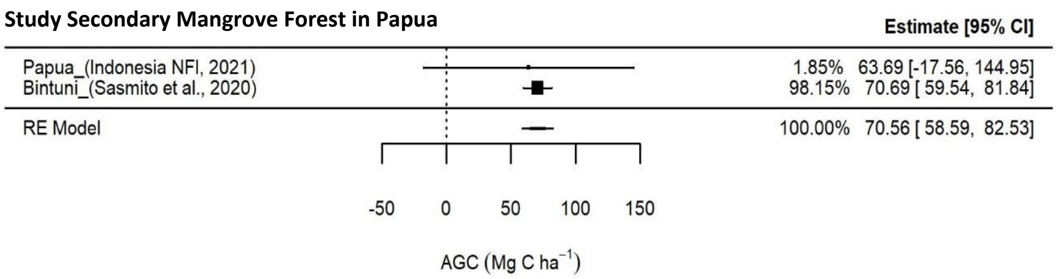

Figure Annex 4.4. Forest plot the estimates of AGB stocks in Mangrove Forest in Indonesia

Table Annex 4.5. Summary of the estimates of biomass stocks in Indonesia mangrove forest (by Main Island)

Main Island	Forest Type	Mean AGB (t.d.m ha^{-1})	95% Confidence Interval (t.d.m ha^{-1})		N of plot measure ments
Kalimantan	Primary mangrove	247.98	219.51	276.43	136
	Secondary mangrove	155.74	115.38	196.09	19
Papua	Primary mangrove	240.64	185.53	295.74	286
	Secondary mangrove	150.13	124.66	175.60	82
Indonesia	Primary mangrove	236.17	206.19	266.15	538
	Secondary mangrove	118.02	87.04	149.00	187

Table Annex 4.6. The estimates of biomass stock in each forest type in Indonesia (by Main Island)

Forest Type	Main Island	AGB tree (t.d.m ha^{-1})		AGB Sapling (t.d.m ha^{-1})		AGB Understorey (t.d.m ha^{-1})		Mean BGB (t.d.m ha^{-1})		Mean Litter (t.d.m ha^{-1})		Mean Deadwood (t.d.m ha^{-1})	
		Mean	**se**	**Mean**	**se**	**Mean**	**se**	**Mean**	**se**	**Mean**	**se**	**Mean**	**se**
Primary Dryland Forest	Bali Nusa Tenggara	278.50	11.69	0.56	0.02	1.40	0.06	81.33	3.39	8.37	0.35	50.51	2.10
	Java	345.46	51.35	0.69	0.12	1.73	0.30	100.89	17.29	10.38	1.78	62.65	10.74
	Kalimantan	323.63	10.05	0.65	0.02	1.62	0.05	94.51	2.89	9.73	0.30	58.69	1.80
	Maluku	236.20	19.01	0.47	0.04	1.18	0.10	68.98	5.88	7.10	0.61	42.84	3.65
	Papua	266.70	9.12	0.53	0.02	1.34	0.05	77.88	2.63	8.02	0.27	48.37	1.63
	Sulawesi	246.55	7.44	0.49	0.01	1.24	0.04	72.00	2.14	7.41	0.22	44.72	1.33
	Sumatra	338.35	10.17	0.68	0.02	1.70	0.05	98.81	2.93	10.17	0.30	61.36	1.82
	Indonesia (Average)	289.21	4.35	0.58	0.01	1.45	0.02	84.46	1.25	8.69	0.13	52.45	0.77
Secondary Dryland Forest	Bali Nusa Tenggara	133.61	7.09	1.47	0.08	3.65	0.19	40.23	2.11	3.65	0.19	44.58	2.34
	Java	202.04	13.25	2.22	0.14	5.52	0.36	60.84	3.97	5.52	0.36	67.41	4.40
	Kalimantan	214.69	4.48	2.36	0.05	5.86	0.12	64.64	1.32	5.86	0.12	71.63	1.47
	Maluku	162.59	8.42	1.79	0.09	4.44	0.23	48.96	2.52	4.44	0.23	54.25	2.79
	Papua	216.48	10.99	2.38	0.12	5.91	0.30	65.18	3.27	5.91	0.30	72.22	3.63
	Sulawesi	159.99	5.46	1.76	0.06	4.37	0.15	48.17	1.62	4.37	0.15	53.38	1.79
	Sumatra	213.28	6.20	2.35	0.07	5.82	0.17	64.22	1.84	5.82	0.17	71.16	2.03
	Indonesia (Average)	196.57	2.72	2.16	0.03	5.37	0.07	59.19	0.80	5.37	0.07	65.58	0.89
Primary Swamp Forest	Bali Nusa Tenggara												
	Java												
	Kalimantan	249.92	23.93	28.49	3.23	6.68	0.76	62.72	7.10	4.45	0.50	51.51	5.83
	Maluku												
	Papua	195.37	13.94	22.27	1.58	5.22	0.37	49.03	3.49	3.48	0.25	40.26	2.86
	Sulawesi												
	Sumatra	311.75	35.95	35.54	4.40	8.34	1.03	78.24	9.68	5.56	0.69	64.25	7.95
	Indonesia (Average)	218.10	12.84	24.86	1.45	5.83	0.34	54.74	3.20	3.89	0.23	44.95	2.63
Secondary Swamp Forest	Bali Nusa Tenggara												
	Java												
	Kalimantan	187.05	7.33	20.76	0.80	7.90	0.31	47.46	1.83	4.78	0.18	49.67	1.92
	Maluku												
	Papua	121.29	13.80	13.46	1.55	5.12	0.59	30.77	3.55	3.10	0.36	32.21	3.72
	Sulawesi												
	Sumatra	179.55	7.31	19.93	0.80	7.58	0.30	45.55	1.83	4.59	0.18	47.68	1.92
	Indonesia (Average)	177.43	4.94	19.69	0.54	7.49	0.21	45.01	1.23	4.53	0.12	47.11	1.29
Primary Mangrove Forest	Bali Nusa Tenggara												
	Java												
	Kalimantan	247.98	14.39	0.00	0.00	0.00	0.00	77.12	4.43	0.00	0.00	14.38	0.83
	Maluku												
	Papua	240.64	28.00	0.00	0.00	0.00	0.00	74.84	8.57	0.00	0.00	13.96	1.60
	Sulawesi												
	Sumatra												
	Indonesia (Average)	236.17	15.26	0.00	0.00	0.00	0.00	73.45	4.66	0.00	0.00	13.70	0.87
Secondary Mangrove Forest	Bali Nusa Tenggara												
	Java												
	Kalimantan	155.74	19.21	0.00	0.00	0.00	0.00	17.91	2.32	0.00	0.00	19.00	2.46
	Maluku												
	Papua	150.13	12.80	0.00	0.00	0.00	0.00	17.26	1.46	0.00	0.00	18.32	1.55

Forest Type	Main Island	AGB tree (t.d.m ha-1)		AGB Sapling (t.d.m ha-1)		AGB Understorey (t.d.m ha-1)		Mean BGB (t.d.m ha-1)		Mean Litter (t.d.m ha-1)		Mean Deadwood (t.d.m ha-1)	
		Mean	se	Mean	se	Mean	se	Mean	se	Mean	se	Mean	se
	Sulawesi												
	Sumatra												
	Indonesia (Average)	118.02	15.72	0.00	0.00	0.00	0.00	13.57	1.78	0.00	0.00	14.40	1.89

Methods for estimating non-natural forest carbon stock

In this 2nd FRL, non-forest above-ground carbon stock was calculated based on the literature review of various studies conducted in Indonesia. The non-natural forest carbon stock from publications was estimated based on the destructive sampling method and allometric equation method. In order to ensure the quality of data, the mean of carbon stocks was compared to IPCC (2006) values for non-forest cover carbon stock. The values were included in the database if they were within the IPCC value range. Meanwhile, if the values were far outside the range, further review was conducted by considering the methods used in the publications. If the publications applied proper carbon inventory methods, the values is included in the database.

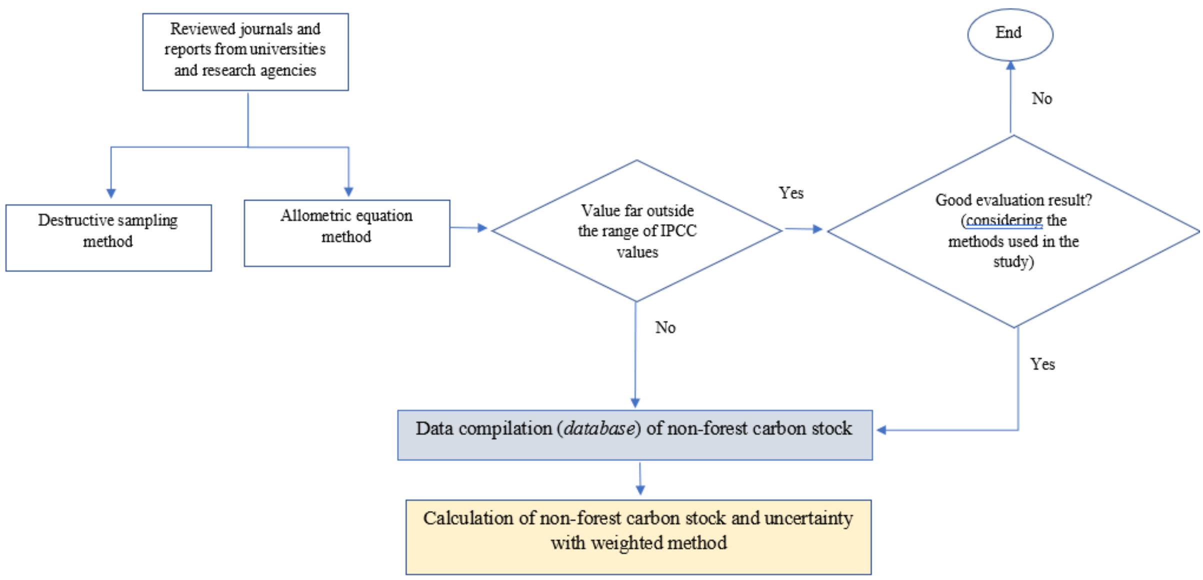

Figure 4.5. Flow chart of the quality assurance of non-carbon stock database development

The total number of observations included in the database is 182 from 57 publications. Meanwhile, land cover classification for non-forest classes refers to the 1st FREL. Plantation forest has the highest number of observations, followed by estate crop. However, several land cover classes have few observations due to limited studies. Therefore, the number of observations of each land cover class is presented in the following table.

Table Annex 4.7. Number of observations on non-forest carbon stock studies

Land cover class	n observation	Source
Plantation forest	49	Agus et al. (2001), Agus et al. (2013), Fauzi et al. (2011), Ginting (2018), Gintings (1997), Hairiah et al. (2001), Hardjana (2010), Kuncoro et al. (2020), Markum et al. (2014), Palm et al. (1999), Prakosa et al. (2012), Rahayu and Pambudi (2017), Rahmat et al. (2007), Ramadhan et al. (2013), Rochmayanto et al. (2010), Sarjono et al. (2017), Sumarga et al. (2020), Syam'ani et al. (2012), Uthbah et al. (2017), Wasis et al. (2012), Widhanarto et al. (2016), Yuniawati et al. (2011), Yuningsih et al. (2018)
Dry shrub	24	Agus et al. (2013), Prahara et al. (2015), Azham (2015), Daud et al. (2015), Fauzi et al. (2011), Nakagoshi et al. (2016), Palm et al. (1999), Pramudita et al. (2011), Prasetyo et al. (2011), Rahayu and Pambudi (2017), Ramadhan et al. (2013), Setiawan et al. (2015), Sularso et al. (2011), Sumarga et al. (2020), Susanti and Dariah (2014), Syam'ani et al. (2012), Wasis et al. (2012), Yuningsih et al. (2018)
Wet shrub	8	Agus et al. (2013), Astiani et al. (2017), Istomo (2006), Istomo et al. (2007), JICA (2009), Rahayu and Pambudi (2017), Solichin and Steinmann (2011), Syam'ani et al. (2012), Syam'ani and Nugroho (2012)
Savanna and grasses	10	Daud et al. (2015), Hairiah et al. (2001), Palm et al. (1999), Prasetyo et al. (2011), Rahayu et al. (2005), Roshetko et al. (2002), Solichin and Steinmann (2011), Sularso et al. (2011), Wasrin et al. (2000)
Pure dry agriculture	4	Agus et al. (2013), Murdiyarso and Wasrin (1995), Wasis et al. (2012)

Land cover class	n observation	Source
Mixed dry agriculture	23	Astiani et al. (2017), Idris et al. (2013), Markum et al. (2014), Nakagoshi et al. (2016), Palm et al. (1999), Rahayu et al. (2005), Ristiara (2017), Roshetko et al. (2002), Setiawan et al. (2015), Sularso et al. (2011), Syam'ani and Nugroho (2012), van Noordwijk et al. (2000), Wardah et al. (2013), Wiryono et al. (2016),
Estate crop	43	Agus et al. (2013), Astriani et al. (2018), Ginting (2000), Guillaume et al. (2018), Tiara (2016), Hairiah et al. (2001), Markum et al. (2014), Monde (2009), Khasanah et al. (2015), Palm et al. (1999), Pramono (2018), Pramudita et al. (2011), Prasetyo et al. (2011), Ramadhan et al. (2013), Setiawan et al. (2015), Sitompul and Hairiah (2000), Sularso et al. (2011), Syam'ani et al. (2012), Syam'ani and Nugroho (2012), van Noordwijk et al. (2000), Wardah et al. (2013), Wasis et al. (2012), Wasrin et al. (2000)
Paddy field	7	Pramudita et al. (2011), Rahayu et al. (2005), Setiawan et al. (2015), Sularso et al. (2011), Syam'ani and Nugroho (2012), Wasis et al. (2012), Wasrin et al. (2000)
Transmigration areas	1	Agus et al. (2013)
Settlement	3	Agus et al. (2013), Syam'ani and Nugroho (2012), Wasis et al. (2012),
Bare ground	3	Agus et al. (2013), Nakagoshi et al. (2016), Syam'ani and Nugroho (2012)
Mining areas	2	Agus et al. (2016), Agus et al. (2013)
Fish pond/aquaculture	1	Agus et al. (2013)
Open water	2	Agus et al. (2013), Syam'ani and Nugroho (2012)
Open swamp	2	Agus et al. (2013), Syam'ani and Nugroho (2012)
Total	**182**	

For forest plantation, above-ground carbon stock was categorized into fast-growing species (FGS), such as Acacia and Gmelina, and slow-growing species

(SGS), such as teak and pine. These species have the largest area in Indonesia, in which about 70% of the plantation area is FGS and 30% is SGS. Using the life-time average (LTA) approach, the rotation cycle of fast-growing species is assumed to be 12 years, and slow growing species is 30 years (Ministry of Forestry, 2009). The equation used to estimate a life-time average carbon stock is as follows (Hairiah and Rahayu, 2007):

$$C_{LTA} = ((Cstock/age)*rotation\ cycle)/2$$

The mean of LTA stock was further weighted based on the area proportion of fast-growing plantations and slow-growing species in Indonesia to estimate the total above-ground carbon stock in plantation forests (Table Annex 4.8).

Table Annex 4.8. Weighted mean of above-ground carbon stock in plantation forest

Land Cover	C stock mean (tC ha^{-1})	Stdev	n	SE	95%CI	U(%)	Area proportion	Weighted C stock (tC ha^{-1})	Combined U (%)
Plantation forest-FGS	59	36	23	8	16	27	0.7	41.10	
Plantation forest-SGS	116	54	26	11	22	19	0.3	34.67	
Total								75.78	15.48

A similar approach was also used to estimate carbon stock in estate crop areas in which a weighted mean was estimated based on the area of each crop (Indonesia Statistics Agency, 2020). The most dominant crop in Indonesia is oil palm (92%), followed by rubber (5%). Meanwhile, coffee and cocoa only contribute to about 3% of the total estate crop area.

Table Annex 4.9. Weighted mean of above-ground carbon stock in estate crop

Land Cover	Cstock mean (tC ha^{-1})	Stdev	n	SE	95%CI	U(%)	Area proportion	Weighted C stock (tC ha^{-1})	Combined U (%)
Estate crop - others	48	34	21	7.46	15.6	32.48	0.03	1.54	
Estate crop - Oil Palm	47	15	16	3.87	8.3	17.75	0.92	42.89	
Estate crop - Rubber	79	35	6	14.24	36.6	46.13	0.05	3.68	
Total								**48.10**	**23.37**

For above-ground carbon stock estimation in dry shrub and mixed dryland agriculture, the mean was weighted based on area proportion from crown cover analysis from Hansen and MoEF land cover map data.

Table Annex 4.10. Weighted mean of above-ground carbon stock in dry shrub

Crown Cover (%)	C stock mean (tC ha^{-1})	Stdev	n	SE	95%CI	U(%)	Area proportion	Weighted C stock (tC ha^{-1})	Combined U (%)
<10	9	5	11	1.48	3.3	37.69	0.01	0.12	
10-30	24	4	5	1.94	5.4	22.32	0.08	1.95	
30-50	34	2	5	0.90	2.5	7.40	0.16	5.31	
>50	71	24	3	13.96	60.1	84.64	0.75	53.01	
Total								**60.39**	**43.99**

Table Annex 4.11. Weighted mean of above-ground carbon stock in mixed dryland agriculture

Crown Cover (%)	C stock mean (tC ha^{-1})	Stdev	n	SE	95%CI	U(%)	Area proportion	Weighted C stock (tC ha^{-1})	Combined U (%)
<10	13	3	4	1.72	5.5	41.74	0.03	0.39	
10-30	25	5	3	2.75	11.8	48.30	0.06	1.56	
30-50	37	2	5	0.68	1.9	5.16	0.26	9.41	
>50	82	14	11	4.29	9.6	11.66	0.65	53.28	
Total								**64.64**	**10.42**

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