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 the third country in the world with the largest tropical rain forests, that provide high biodiversities, environmental services as well as socio economi benefits for the past, current and future generations. Sound management of remaining forests for economic purposes and biodiversity conservation are keys for sustainable use of natural forest resources. Our efforts in protecting the remaining high conservation value forests and better managed the production forests yielded tangible results in the form 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, we are aiming at reducing the emission level by 29% on our own resources or up to 41% with international support. Forestry sector shares the largest contribution of emission reduction target, i.e., 17.2% using our own resources and 24.1% with international supports. Out of which, 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/GHG emission reduction activities in the forestry sector, particularly through the implementation of REDD+.

Following the Warsaw Framework, parties that 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+ requirement that used as a reference in measuring the performance of the successful implementation of REDD+. Referring to the mandate of the UNFCCC COP in Decision 12/CP.17 paragraph 12, FREL/FRL needs to be updated periodically taking into account scientific developments, changing emission trends, as well as any modifications to the scope and methodology. FREL/FRL submitted/submitted to the UNFCCC will be verified through a technical assessment process by the UNFCCC Secretariat.

Our first National 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.

In the 1stNational FREL document there is a plan of improvement that will be carried out in the next National FREL update. Based on the plan of improvement and taking into account the need for updating data and information as well as updating the methodology and scope in accordance with national and sub-national developments, Indonesia has updated the National FREL.

Several things were updated in the National 2nd FREL/FRL document, including:

a. REDD+ activities and emissions taken into account include: deforestation, forest degradation and enhancement of forest carbon stock, decomposition of peat, fires (peat and minerals) in areas experiencing deforestation or forest degradation, and emissions from conversion of mangrove forests into cultivated areas.

b. The calculated carbon pool includes all carbon pools (Above Ground Biomass, Below ground Biomass, dead wood, litter, soil).

c. The inclusion of the calculation of emissions from Non-CO_2 gases (CH_4 and N_2O) from forest and land fire activities in areas experiencing deforestation or forest degradation.

d. Calculation method used: net emission

e. Improvements in the calculation of uncertainty

This National 2nd FREL/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 Drafting Team of the National 2nd FREL/FRL for their contribution in devoting thoughts, energy, time, and resources. funding in the preparation of the National 2nd FREL/FRL, so that this National 2nd FREL/FRL document can be realized. Thanks are also conveyed to the UNFCCC expert who will conduct a 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 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 improvement plan that was stated in the previous FREL. This FREL/FRL which is the FRL, will not revised or affecting results of the previous use of FREL as forestry baseline in all GHG reports such as the 2nd Bienneal Update Report (BUR) and the REDD+ Technical Annex, Third National Communication, as well as National GHG Emission Report. This submission meets the COP requirements of the COP by following the guidance for technical assessment and adopting the principals of transparency, accuracy, completeness, 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. Stepwise approach to the calculation of the FRLwas 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 consistency with the data used. The scope of the area for the FRL calculation is the land area of Indonesia that was covered by natural forest in year 2006, accounted for 94.9 million ha and 92.3 million hectares of non forest cover represent approximately 50.7% of the country's land area. This includes primary and secondary forests, irrespective of the state of forests within the national forest area defined by MoFor (2014). Peatlands outside this area were excluded but will be included in the BUR. 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 selected as pools included in this FRL. In addition, CO_2, CH_4 and N_2O were the selected greenhouse gasses 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 UNFCCC experts in 2016. 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 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 development of the FREL/FRL, in accordance with paragraph 10 of Decision 12/CP.17 for the purpose of improving the national FREL. Thus, the improvement of the FREL/FRL is doned 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 for voluntarily submission of the Updated FREL/FRL. The Updated FREL not only covers emissions from deforestation and forest degradation, but also includes activities of enhancement of forest carbon stocks, so the term become FRL. In this submission, Indonesia takes the opportunity to include also gas and carbon pools that contribute significantly to the national GHG emissions.

Indonesia underlines that the submission of the FRL is voluntary and exclusively for the purpose of obtaining and receiving payments for REDD+ activities, in accordance with 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 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 organisations. Indonesia will ensure, as far as possible, maintain the principles of TACCC and avoid double-counting and double-payment.

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

2. Improvement from Previous Submissions

This document builds on the 1st FREL for the REDD+ submitted in 2015, and have been technically assessed by UNFCCC Secretariat in 2016. The 1st FREL document has been designed to be used as a reference for evaluating the performance of Indonesia REDD+ implementation in 2013 to 2020. Indonesia requires submitting the 2nd submission for a post-2020 REDD+ implementation reference.

Indonesia retains the similarity to the 1st FREL document, and considered this as an updates of the first submission, which is consistent with Decision 12/CP.17. However, this submission also considers the improvement plan identified in the 1st submission, the suggestions of the UNFCCC Secretariat's technical assessment, and lesson learn or experiences on REDD+ frameworks in Indonesia such as the Indonesian-Norwegian Partnership and the East Kalimantan FCPF Carbon Fund.

The 2nd submission contains significant improvements. In the 1st submission, Indonesia focused only on deforestation and forest degradation and had not taken into account forest regrowth or enhancement of forest carbon stock in the calculation. Therefore the 1st submission was called the Forest Reference Emission Level or FREL document. While the 2nd submission is called FRL document.

The reference period of the FRL has been revised, shorter than FREL, i.e. from the period of 1990 to 2012 (22 years) in the 1st submission to 2006 to 2020 (14 years) in the 2nd submission. Thus the FRL will serve as a benchmark for assessing the emission reductions from the post-2020 period, i.e. 2021 – 2030.

Similarly, Indonesia also added a number of activity data for the calculation purposes. In the 1st submission, activity data covered only the National Forest Monitoring System (NFMS) land cover maps and peatland distribution map. Whereas now, burned scar area map due to forest fires generated from the NFMS, is also used in the calculation, in particular to estimate peat soil fire emissions and biomass burning.

Emission factors were significantly improved in the 2nd submission. In the 1st submission, the emission factor for estimating emissions from deforestation and forest degradation only covered the AGB for forest classes, whereas in the 2nd submission, it has been into calculation. The emission factors or biomass stock of the non-forest classes were also considered. Soil carbon emission factors for estimating wetland (peat soil and mangrove soil) emissions due to forest conversions have also been significantly improved. Indonesia also included soil carbon emission factors to estimate emissions from peatlands fires.

The pools and gases were enhanced in the 2nd submission, in which pools of AGB, DOM, and SOC (for peat decomposition, mangrove conversion, and peat fires) were considered. The N_2O and CH_4 gases were also included in the calculation, in addition to CO_2.

The scope of the present FRL document covers an area of 94.9 million hectares of forests in 2006, and 92.3 million hectares of non-forests. The forest area equal to 50.7% 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 forest carbon stock
Scope of Areas	113.2 million ha of natural forests in 1990	94.9 million ha of forests in 2006 and 92.3 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	NFI 1990-2013 with complementary research data for mangrove forests[b] 2014 IPCC Guidelines on Wetland Suppplement	NFI 1990-2013; NFI 2014 – 2020 in particular for mangrove forests. 2014 IPCC Guidelines on Wetland Suppplement 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 emphasis in peat decomposition	AGB, BGB, and SOC with emphasis in peat decomposition, mangrove conversion, and peat fires. In addition, AGB, deadwood and litter were also accounted for biomass burning

3. Definitions Used

3.1. Forest

Indonesia formally defines forest as "a land area of more than 0.25 hectares with trees higher than 5 metres at maturity and a canopy cover of more than 30 percent, or trees able to reach these thresholds in situ" (MoFor, 2004). The forest definition for this submission is aligned with the official Indonesian definition, as well as 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 emphasises 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, particulary 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 metres 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. Land cover classes used in the Forest Reference Emission Level

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 classes are land cover classes other than forest, including cropland, agriculture land, grassland, shrub, settlement, wetland and other built-up areas. The generation of non-forest maps is part of the NFMS, therefore they have a similar method and accuracy for forest cover maps.

LC Code	Land-cover class	Abbreviation	Category	IPCC
2010	Estate crop	EP	Non-forest	Crop land

LC Code	Land-cover class	Abbreviation	Category	IPCC
20091	Pure dry agriculture	AUA	Non-forest	Crop land
20092	Mixed dry agriculture	MxUA	Non-forest	Crop land
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	Fish pond/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. Peat land

Peatland is defined as an area with an accumulation of decomposed organic matter, saturated with water containing of at least 12% organic material content and cummulative layer of at least 50 cm in depth (Noor and Anda, 2021). The definition folows the commonly used definition of global peat soil of the USDA Soil Taxonomy. The updated peatland distribution map used in this submission is the revised version of the maps used in the previous submission, which was updated in 2021 based on medium and high-resolution imageries, further soil survey data and 1:50.000 map scale (Anda et al, 2021).

3.4. Deforestation

In this submission, deforestation is defined as the conversion of natural forest cover to other land-cover categories. This 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 in defining deforestation, which is in line with Decision 1/CP.16 (Appendix 1, paragraph 2(e)).

This submission also takes into account the deforestation that occured 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 submision.

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 as a result of human activities. In this document, forest degradation is defined as the change of primary forest class to secondary forest class. The secondary forest categories (see Table 2) represent forests that have degraded or decreased in quality as a result of selective logging or other external factors which affect the partial loss of primary forest stands.

The second level of forest degradation (i.e. occur 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 is defined as the increase in carbon stock due to conversion of non-forest into forest categories (forest gain). The non-forest categories include agriculture, estate crop, grassland, shrub, settlement and other areas, whereas the forest categories used for assessing the EFCS include primary forests, secondary forests and plantation forests. Conversion from secondary forest categories into primary forest categories is excluded from the calculation because the classification approach for 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 which 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. 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 occured in drained peatlands and peat swamp forests. Drained peatlands pose a major 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 matters and biomass, but also organic soils in peatlands. Peat emission from peat fires are estimated based on the size of burned peatlands that are directly associated with current deforestation and forest degradation. Emissions from the burned of organic soils, biomass and dead organic materials are considered in this calculation.

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

3.9. Mangrove Conversion

Several major drivers of mangrove deforestation which resulted in GHG emissions include conversion to aquaculture, agriculture, and plantations. Pristine mangrove soils provide essential nutrients and living condition for shrimps growth. Development of the shrimp or fishponds normally 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 will not be 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 any changes in scope and methodologies. FRL refers to not just emissions but also removals. The FRL serves as a benchmark for measuring performance in the implementation of REDD+ activities, including avoiding deforestation, forest degradation, peat fires, mangrove conversion, peat decomposition 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 dynamics over the reference period. The reference period used in this FRL is 2006 to 2020. The FRL is projected for the next 10 years to compare actual emissions over the projection period, i.e. in 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 was considered in the estimation of 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 94.9 million hectares of forest and all non-forest categories that were cleared prior to 2006 amounted to 92.3 million hectares. The area covered for emission accounting from deforestation includes areas which in 2006, were covered by natural forests, including both in peatlands (8.3 million hectares) and mineral soils (86.5 million hectares). Area covered by primary forests in 2006 (50.3 million hectares) have been included in the calculation of forest degradation emissions. The area covered for counting EFCS removal include all non-forest categories, that were cleared prior to 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 (97.3 million ha) and non forest classes (92.3 million ha)

4.2. Activities Covered

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

4.3. Pools and Gases

In this FRL, all five carbon pools namely AGB, BGB, litter, dead wood and soil carbon (SOC) are included in the emission calculation. The SOC is included only in relation to peatland and mangrove emissions due to deforestation, forest degradation, fires and mangrove conversion. Changes in SOC stock due to EFCS appear to be insignificant and require a lengthty period of time or lack of robust monitoring method, therefore it is excluded from this submission. Litter and dead wood are included only for non CO_2 emission estimates from fires.

Carbon dioxide was the only GHG gas reported in the FREL, while CH_4 and N_2O gases are also reported in the FRL. Carbon dioxide emissions were derived from biomass and soil-related emissions from deforestation, forest degradation and EFCS, including peat fires, the decomposition of peat and conversion of mangroves. Whereas, 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 key for estimating GHG emissions. Data used for FRL development should be selected based on the principles of transparency, accuracy, completeness and consistency (TACC). Specifically, it is recommended to use the best available data with known uncertainty, where future improvements are are acknowledged. In addition, all data used for FRL development are generated based on the scientifically approved methods or as part of the national system that managed by a credible data custodian under the Government of Indonesia. Therefore, this ensures the consistency, transparency and continuity of the data to be reproduced in the future for the purpose of independent review, repeated measurement of the annual emissions and calculation of emission reductions as a result of REDD+ implementation. In addition, the data sets used for this submission are consistent with other national reports for Global Forest Resource Assessment (GFRA), 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 which is accessible via the NFMS website (http://dbgis.menlhk.go.id/arcgis/rest/services/Simontana) and links to 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 wall-to-wall land cover maps were derived from Landsat satellite images. The series of land cover maps were digitised manually for each monitoring year through visual interpretation of satellite imageries. Indonesia has generated the land cover data since 2000 (see Annex 1).

Furthermore, the land cover maps are used for generating the activity data of deforestation, forest degradation and enhancement of forest carbon stock. To produce activity data of deforestation, the natural forest categories of the initial year of the reference period and the non-natural forest categories of the last year of the reference period were selected for the development of the transition tables that quantified the extent of deforestation and types of non-natural forest categories after the deforestation. Similarly, for forest degradation, the primary forests of the initial year and the secondary forests of the previous year of a specific reference period were selected for the development of the forest degradation transition tables. To generate activity data for enhancement of forest carbon stock, we selected the non-forest categories of the initial year that changed into forest categories in the last year, in particular the secondary forest category.

5.1.2. National peat land data

The peat land spatial data used in this FREL was provided by the MoA, based on several related maps, field survey and accompanied ground check verification. The newly updated peatland distribution map used in this submission is the revised version of the maps used in the previous submission, 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 version of the map (1:250,000 map scale). The map is published in the One Map Web GIS, at https://portalksp.ina-sdi.or.id. More detailed method on peatland mapping is presented in Annex 2.

5.1.3. Burnt areas

Fires in peatlands has become a significant source of emissions. Although most of the fire that occurred in 2015 were from mineral soils (four times larger than fires in peatlands), the emissions that originated from fires in peatlands were six times larger than emissions from fires in mineral soils (MoEF, 2016). Deforested and drained peat swamp forests coupled with prolonged dry seasons create an environment that is susceptible to fires. Once the source of ignition starts, fires in drained peatlands in prolonged dry seasons will easily spread and consumed the biomass and organic matters, including organic soils, and emit huge amounts of GHG and carbon monixide.

The data of burnt areas are produced by MoEF based on visual interpretation of medium resolution of satellite imageries (KLHK, 2021). The maps are produced for the years 2000 to 2020 by IPSDH Directorate and validated using ground thruthing data by *Direktorat Pengendalian Kebakaran Hutan dan Lahan*/Directorate of Forest and Land Fire Control (PKHL) MoEF. To generate activity data of peat fires for this submission, the annual burnt areas on maps are overlaid with peatland maps and annual deforestation and degradation maps. More detailed method on burn area mapping is presented in Annex 3.

5.1.4. Forest carbon 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 programme 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.

For the purpose of FREL, only PSPs data were used for calculation (Tract No. 5). 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, for the mangrove forest, the analysis included the temporary sample plot (TSP) data, which were collected using 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 of the plots with AGB of the plots.

The 2016 FREL used allometric equations from Chave *et al.* (2005) for all forest types, although revised equations were available (Chave *et al.*, 2014). The old equations are simpler than the revised equation, because the revised equations use additional variables related to environmental stress factor (E) that depends on the geographic location. Using of locally developed equations will provide a more accurate and unbiased estimation, than using global equations. Therefore in this submission, the AGB of individual trees in the plots were estimated using an allometric model developed for Indonesia forests (Manuri *et al.*, 2017; Manuri *et al.*, 2014), which used diameter at breast height (DBH), wood density (WD) of the species and region as the key parameters. However, for mangrove forest, allometric equation for mangrove tree species from Chave *et al.* (2005) is more accurate than other allometric for mangrove(Annex 4).

The WD values were taken from the database of the MoEF through the Research, Development and Innovation Agency/FORDA (FORDA, 2012), which is a compendium of WD 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.

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

$$M_P = \sum_1^n \frac{M_T}{A_P} M_P = \sum_1^n \frac{M_T}{A_P} \qquad \text{(Equation 1)}$$

where MP = AGB of plot expressed as (t ha^{-1}), MT = AGB of measured tree (t), AP = plot area (ha), n = number of trees per plot.

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

$$M_j = \sum_{1=1}^n \frac{M_{Pi}}{n} M_j = \sum_{1=1}^n \frac{M_{Pi}}{n} \qquad \text{(Equation 2)}$$

where M_j = mean AGB (t ha^{-1}) of forest type-*j*, MP_i = AGB of plot-*i*, *n*= plot number

Table 3 provides a summary of AGB estimates for six forest types (primary dryland forest, secondary dryland forest, primary swamp forest, secondary swamp forest, primary mangrove forest, and secondary mangrove forest) in some main islands of Indonesia from NFI that were used as the basis for determining the emission factors.

Table 3. The estimates of AGB stocks from NFI in each forest type in Indonesia

Forest type	Main island	N of plot	Mean AGB (Mg ha^{-1})	Std Dev (Mg ha^{-1})	95% Confidence Interval (Mg 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						
	Java						
	Kalimantan	8	249.92	67.68	193.34	306.50	22.6
	Maluku						
	Papua	73	195.37	119.12	167.58	223.16	14.2
	Sulawesi						
	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						
	Java						
	Kalimantan	179	187.05	98.01	172.60	201.51	7.7
	Maluku						
	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						
	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						
	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. Distribution of NFI measurement plots in mangroves forests is still limited, however, there are carbon stocks measurement studies that have been carried out in 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; Nuryanto *et al*., 2020; Sasmito *et al*., 2020). The mean and SE of AGB from NFI data were combined across the studies to derive numbers of AGB for the mangrove forest. The true value of in 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 4.1, Table Annex 4.2).

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. Using the proportions from previous research, the other unmeasured components of carbon pool were estimated by considering the type of forest ecosystem (Verwer and van der Meer, 2010; Krisnawati *et al*., 2014). Table 4 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) that were used as basis for determining the carbon stock in each carbon pools.

Table 4. The estimated ratio value of sapling, understorey biomass, and root to aboveground tree biomass in each forest type in Indonesia

	Ratio to AGB tree (%)		
Forest types	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

To estimate the amount of carbon (C) in each forest type, information on carbon fraction is needed. The carbon fraction of biomass (dry weight) was assumed to be 47% (1 tonne biomass = 0.47 tonnes C) following IPCC 2006 Guideline. Conversion of

C stock 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).

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

Table 5. Emission factor in each forest type in Indonesia

Forest type	**Main island**	**AGB ($Mg\ ha^{-1}$)**		**BGB ($Mg\ ha^{-1}$)**		**Forest Ecosystem ($Mg\ ha^{-1}$)**		**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
	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

Forest type	Main island	AGB (Mg ha^{-1})		BGB (Mg ha^{-1})		Forest Ecosystem (Mg ha^{-1})		U (%)
		Mean	SE	Mean	SE	Mean	SE	
	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

5.1.5. Carbon stock for non-forest categories

The use of carbon stock for non-forest classes is an improvement in 2nd FREL calculation. In the previous FREL calculation, carbon stocks in non forest areas were not incorporated in the estimation of the emission factor of deforestation. Emission estimation from deforestation was based on potential emissions, which assum that all forest carbon stocks will be lost after deforestation (also known as 'gross emission'). This means carbon stock is only counted as a loss by deforestation when natural forests are cleared, without considering post-conversion carbon stocks (FREL, 2016). 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, not only for estimating emissions from deforestation but also for estimating removals from the enhacement of forest carbon stocks.

Abovegound carbon stock for non-forest classes in this document uses life-time average approach, which recognises life cycle in a land system. In this approach, carbon stock in non-forest classes is determined by 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 different land system with various tree growth and rotation (ICRAF, 1996; Watson *et al.*, 2000).

Emission factor for non-forest classes was analysed based on compiled data from reviewed journals and scientific reports from universities and research agencies (N=249). Carbon stocks in non-forest classes were determined using weighting score. For carbon stock estimates in 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 area into two categories, old shrub and young shrub. The combination between canopy cover percentage and carbon stock was used to determine weighting score for each dry shrub category.

Aboveground carbon stock in plantation forest, estate crop, mixed agriculture and transmigration area were also analysed using weighting score. The weighting score for plantation forest 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 analysed based on tree cover percentage from Hansen and land cover map for mixed agriculture and transmigration area. Using the root-to-shoot ratio from IPCC 2019; Gautam *et al*., (2021), the belowground carbon stocks were estimated by considering the ecological zone, non-forest type, and aboveground carbon stock.

Table 6. Non-forest carbon stock in Indonesia

Non-Forest Type	**AGB (Mg ha^{-1})**		**BGB (Mg ha^{-1})**		**Total Ecosystem[1)] (Mg ha^{-1})**		**U[2)] (%)**
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	
Plantation forest	75.78	7.52	24.63	2.44	100.40	7.91	15.44
Dry shrub	60.39	7.22	14.25	1.70	74.64	7.42	19.48
Estate crop	48.10	6.90	15.63	2.24	63.74	7.25	22.30
Settlement	2.17	1.17	0.63	0.34	2.80	1.21	85.18
Bare ground	2.40	1.36	0.57	0.32	2.97	1.39	92.17
Savanna and Grasses	4.06	1.94	0.96	0.46	5.02	2.00	77.88
Open water	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet shrub	19.34	3.97	4.56	0.94	23.91	4.08	33.42
Pure dry agriculture	14.08	7.70	2.82	1.54	16.89	7.85	91.10
Mixed dry agriculture	64.64	2.30	12.93	0.46	77.56	2.35	5.93
Paddy field	10.00	3.88	2.36	0.92	12.36	3.99	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	14.08	7.70	2.82	1.54	16.89	7.85	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

5.1.6. Peat and forest fires emission factor

Land clearing by human activities has affected the extent of fire in Indonesia. Large fires in 2015 and 2019 have resulted in major losses of carbon and increased carbon dioxide and other trace gases to the atmosphere. With the recognition of the peat fire as a significant carbon source in Indonesia, CO_2 and CH_4 emissions from peat fires are incorporated in this FRL. Peat fires are a key category in Indonesia and it is strongly recommended to report emissions by applying the highest tier possible (IPCC, 2014). Here, we conducted a meta-analysis of primary peat fires studies conducted in Indonesia (Table 7) to define relevant parameters for estimating peat fire emissions.

Table 7. 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)	237.27 (32.48)	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 GWP (AR5)= 28
BD (bulk density)	0.16 (0.015)	g cm-^{3}	Konecsny 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; Konecsny *et al*. 2016; Usup *et al*.2004; Page *et al*.2002; Saharjo 2007; Simpson *et al.*2016; Saharjo and Munoz 2005

GHG emissions from peat burning were determined by applying updated variables derived from the meta-analysis from peat fire studies in Indonesia. To derive higher tier emissions factor, the values for combustion factor, emission factor (ef) for each gas (CO_2 and CH_4), bulk density, and peat burn depth were analysed from published literatures, instead of applying the default value of emission factor from IPCC (2014). Data were compiled and analysed using a meta-analysis approach. 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 (10cm – 40cm). Emission factors of CO_2 and CH_4 were analysed from the 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 (e.g Stockwell 2015) and remote sensing approaches (Ballhorn *et al*. 2009; Huijnen *et al*; Konecsny *et al*. 2016) which covered wildfires and controlled burning studies (Saharjo 2007; Saharjo and Munoz 2005).

Table 8. 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

Emission factors for estimating non-CO_2 emissions from biomass burning, were derived from 2006 IPCC guidelines, i.e. combustion factors and emission factor for each gas of dry matter burnt. While the fuel mass was generated from the AGB and DOM of each forest type (Table 8. Emission factors for non-CO2 emissions from biomass burning.

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 forest should be quantified properly based on the current Indonesia monitoring system (Landsat).

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 from several land use types in Indonesia. Although the GHG emissions database of tropical peatlands has been recently updated (Prananto *et al*., 2020), we realised that there are still some issues related to references, including duplicated measurement, non-peer reviewed articles and methodology discrepancies in the paper. 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. There is a synchronisation in the reported land use category from publication with Indonesia's land cover classes. Afterward, we reanalysed the original datasets derived from reviewed literature (N=274) to update the emission factor of each gas. For studies that reported total soil emissions, we converted to heterotrophic respiration only using the percentage of heterotrophic respiration contribution to total respiration. Heterotrophic respiration is a better representation of the carbon losses from the decomposition of soil organic matter by microorganisms (Hergoualc'h *et al*., 2017). Based on our analysis, heterotrophic contribution to total soil respiration are 68% and 75% for secondary forest and other land cover types, respectively. Primary forest is assumed to produce zero soil emissions.

Excessive drainage of peatlands and N fertiliser application in plantations bring negative impacts not only on CO_2 emissions (Zhou *et al*., 2014) but also on N_2O emissions (Hatano, 2019). Even though studies on N_2O emissions are limited compared to CO_2 emission study, the annual application of N fertiliser to agricultural sites on peatlands have significant impacts on total GHG emissions.

Primary and secondary peat forests are differentiated based on the site description from literatures, 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 water-table depth and land use type (Carlson *et al*. 2015; Hoojier *et al*. 2012; Wakhid *et al*. 2017; Prananto *et al*., 2020). For peatland converted to transmigration, settlement and mining areas, the emission factors utilised have been 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 9 shows the summary of updated EF for CO_2 emissions (Mg CO_2 ha^{-1} yr^{-1}) from various land cover types in Indonesia.

Table 9. Emission factors of peat decomposition from various land cover types

Land Cover	**Mean (Mg CO_2 $ha^{-1}yr^{-1}$)**	**95% Confidence Interval (Mg 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

Land Cover	Mean ($Mg\ CO_2\ ha^{-1}yr^{-1}$)	95% Confidence Interval ($Mg\ CO_2\ ha^{-1}yr^{-1}$)		Uncertainty %
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
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, all mangrove conversion to aquaculture will apply the emission factor based on potential emissions of soil loss due to soil excavation. Mangrove on peat soil converted to cultivated lands other than aquaculture used the emission factor for peat decomposition.

Table 10. 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	Afianti et al, 2019
Conversion to fishpond	Mineral	90.06	22.82	Afianti et al, 2019
Conversion to cultivated land	Peat	*See Table 9*	*See Table 9*	*IPCC (2014)*
Conversion to cultivated land	Mineral	28.97	5.75	IPCC (2014)

5.2. Methodology and Procedures

The principal guideline for establishing FREL/RL 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 a variety of methodologies that are available (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 the availability of land cover data that is transparent, accurate, complete and consistent and reflection 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 2006/2009 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 of forest and land cover categories over monitoring periods. The analysis of annual land cover change involves 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 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” is land cover; “T_0” is previous year; ”T_1” is current year; “NF” is natural forest categories, which include primary forests (“PF”) and secondary forests (“SF”); “F” is forests, which include timber plantation; “Def” is deforestation; “Deg” is forest degradation; “$ECS_{NonF\text{-}F}$” 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 BA are peatland and burned area, respectiveley.

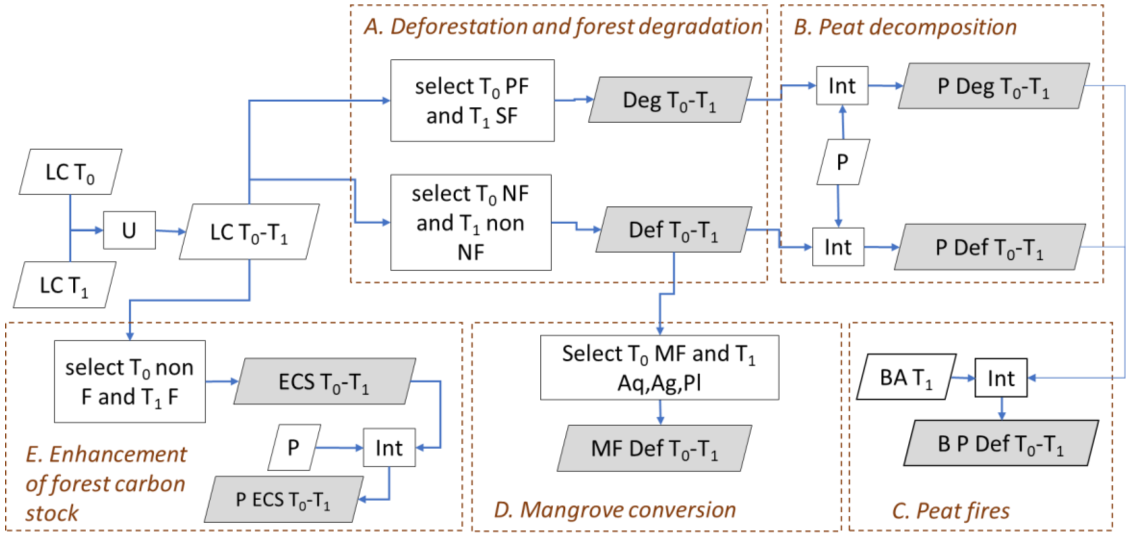

Figure 2. Flow chart of forest and land cover change analysis for generating activity data.

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 forest 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 peat decomposition activity data, we intersected the deforestation and forest degradation activity data with peatland data (Figure 2B). All deforestation and forest degradation areas that were in peatlands were considered for generating activity data of peat decomposition.

We further 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 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 2D). The cultivation areas included agriculture, aquaculture, estate crops and plantation.

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

5.2.3. Emission calculation from peat decomposition

Emissions from peat decomposition are calculated folowing the Equation 6 by multiplying the activity data (i.e. deforested and degraded peatlands) in hectare with the emission factor of the subsequent land cover in tonne carbon per hectare.

$$PDE_{ijt} = A_{ijt} \times \left(\frac{EF_{T1j} + EF_{T2j}}{2}\right) \qquad \text{(Equation 6)}$$

Where *PDE* is CO_2 emission ($tCO_2\ yr^{-1}$) from peat decomposition in peat forest area-i changed into land cover type-j within time period t. *A* is area-i of peat forest changed into land cover type-j within time period t. EF_{T1j} and EF_{T2j} are the emission factors from peat decomposition of land cover class-j from T_1 and land cover class-j from T_2, respectively ($tCO_2\ ha^{-1}\ yr^{-1}$).

5.2.4. Emission calculation from deforestation and forest degradation

Emission from deforestation and forest degradation (GE_{ij}) were estimated based on the multiplication of the activity data on the deforestation and degradation area-i (A_{ij}) in hectare, with the emission factor of the associated forest cover change type-j (EF_j) in tonne carbon per hectare. A conversion factor from C to CO_2, equals to 44/12, was further multiplied to derived emissions in tCO_2 equivalent (Equation 3).

$$GE_{ij} = A_{ij} \times EF_j \times (44/12) \qquad \text{(Equation 3)}$$

Emission from gross deforestation and forest degradation at period t (GE_t), was estimated using equation 4:

$$GE_t \sum_{i=1}^{N} \sum_{j=1}^{P} GE_{ij} \qquad \text{(Equation 4)}$$

where, GE_t is in tCO_2, GE_{ij} is emission from deforested or degraded forest area-i in forest classes j, expressed in tCO_2. N is number of deforested or degraded forest area units at period t (from t_0 to t_1), expressed without unit. P is number of forest classes which meet natural forest criterion.

Mean emissions from deforestation and forest degradation from all period P (MGE_P) were calculated using equation 5.

$$MGE_P = \frac{1}{T} \sum_{t=1}^{p} GE_t \qquad \text{(Equation 5)}$$

Where, MGE_P is expressed in tCO_2yr^{-1}. GE_t is total emissions from gross deforestation and forest degradation at year t and expressed in tCO_2. T is number of years in period P.

5.2.5. Emissions calculation from peat fires

Emissions from peat fires are calculated using following equation (IPCC, 2014)

$$E_{pf} = AD_{pf} \times DB_{pf} \times BD \times Cf_{pf} \times EF_{pf} \times 10 \qquad \text{(Equation 6)}$$

Where E_{pf} is the mission from burned peatland in tCO_2, AD_{pf} is the activity data of burned peatland in deforested areas in hectares, DB_{pf} = average burned peat depth in metre, BD is bulk density of peat soil in $t.m^{-3}$, Cf_{pf} is combustion factor , EF_{pf} is emission factor of burned pet soil in $g.kg^{-1}$.

To avoid double counting with emissions calculation from deforestation and forest degradation, we include only soil organic carbon pool and non- CO_2 gas for estimating emissions from peat fires.

5.2.6. Emissions calculation from mangrove conversion

Emissions from mangrove conversion are calculated using the following equation

$$E_{aq} = AD_{aq} \times EF_{aq} \qquad \text{(Equation 7)}$$

Where E_{aq} is emissions from deforestation for aquaculture development in tCO_2, AD_{aq} is activity data of aquaculture development after deforestation, EF_{aq} is the emission factor for soil extrcation in aquaculture development.

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 period of monitoring. Meanwhile, this analysis covers only the development of aquaculture that are previously mangrove forests.

5.2.7. Removals calculation from enhancement of forest carbon stock

Removals from mangrove conversion are calculated using the following equation

$$R_{ECS} = \left(AD_{ECS\_NonF-F} \times EF_{ECS\_NonF-F}\right) \qquad \text{(Equation 8)}$$

Where R_{ECS} is removals from enhancement of forest carbon stock in tCO_2, AD_{ECS_NonF-F} is activity data of enhancement of forest carbon stock from conversion of non-forest to forest categories, EF_{ECS_NonF-F} is the emission factor for enhancement of forest carbon stock from conversion of non-forest to forest categories.

5.2.8. Reference level calculation

Reference level (RL) was calculated based on the average emissions and removals of REDD+ activities from the reference period, i.e. from historical emissions from deforestation and forest degradation and removals from ECS. Reference level of each activity (RL_j) was calculated using stock-difference method based on carbon stock of the initial year (C_{T1j}) and the last year (C_{T2j}) from activity j then devided by baseline years.

$$RL_j = \frac{(C_{T1j} - C_{T2j})}{(T_2 - T_1)} \qquad \text{(Equation 9)}$$

For estimating the reference levels from peat decomposition, the emission level at the last year deducted by emission level at the initial year then devided by baseline years (see below equation).

$$RL_j = \frac{(E_{T2j} + E_{T1j})/2}{(T_2 - T_1)}$$

Where E_{t1j} and E_{t0j} are emissions of activity j from first year (T_1) and last year (T_2), respectively.

Historical emissions from peat decomposition, fires and mangrove conversion were calculated for the same base period as deforestation, forest degradation and enhancement of forest carbon stock.

5.2.9. Uncertainty calculation

Uncertainty analysis is required to quantify the combined uncertainty of emission and removal estimates using Mote 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 overall uncertainty of the estimates.

In this study, we used a simple spreadsheet template for uncertainty analysis using Monte Carlo simulation[2]. The spreadsheet used a combination of approach 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. First we generated the mean and standard deviation or standard error of all ADs and EFs (from each pool and gas). The means of AD for each activity were data taken from the forest and land cover change database. Standard error of AD was estimated based on the approach suggested by Olofsson *et al*. (2014) and Probability Density Function

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

(PDF) was defined to estimate the 2.5% and 97.5% quantiles that define the lower and upper uncertainties of the total emissions from a category. Therefore, 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 estimated, and the process was repeated 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 in the period of 2006/2007 to 2019/2020 was 755.5 thousand hectares. Secondary drylands and secondary swamp forests were the most deforested with 453.7 thousand hectare and 220.8 thousand hectares annually. The land use/land cover type after conversion was dominated by estate crops, dry shrubs and estate crops, which accounted for 214.4 thousand hectares, 146.7 thousand hectares and 136.4 thousand hectares, respectively.

Table 11. Annual deforestation occured during the reference period

Forest Strata	AD Deforestation (ha yr^{-1})	SE (ha yr^{-1})
Primary dryland forest	37,362.61	2,485.12
Secondary dryland forest	453,680.23	30,175.93
Primary mangrove forest	3,857.72	256.59
Primary swamp forest	21,715.41	1,444.37
Secondary mangrove forest	18,035.01	1,199.57
Secondary swamp forest	220,822.27	14,687.70
Total	755,473.25	50,249.28

Table 12. Post-conversion land use categories after deforestation

Strata	AD Post Deforestation (ha yr^{-1})	SE (ha yr^{-1})
Plantation forest	75,707.76	5,035.60
Dry shrub	146,672.58	9,755.73
Estate crop	214,407.23	14,261.01
Settlement	5,421.17	360.58
Bare ground	30,918.14	2,056.48
Savanna and Grasses	11,406.31	758.68
Open water	4,716.66	313.72
Wet shrub	83,729.35	5,569.15
Pure dry agriculture	22,328.80	1,485.17
Mixed dry agriculture	136,415.25	9,073.48

Strata	AD Post Deforestation (ha yr^{-1})	SE (ha yr^{-1})
Paddy field	4,771.56	317.37
Fish pond/aquaculture	6,735.66	448.01
Port and harbour	75.01	4.99
Transmigration areas	422.47	28.1
Mining areas	8,699.80	578.66
Open swamps	3,045.49	202.57
Total	755,473.24	50,249.30

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 154,130 ha/year and occurred mainly in secondary swamp forests (87.8%) and primary swamp forests (9%). The least significant deforestation on peatland was the deforestation of primary mangroves, with only 61 ha or 0.04% of the total deforestation on peatlands (Table 13). Further analysis revealed that most of the natural forest deforestation on peatlands has been converted to estate crop (38.8%), wet shrub (27.7%), and plantation forest (21%) (Table 14). Mangrove conversion for cultivation in peatland, was also quantified for the activity data for peat emission calculation. During the reference period, the conversion of mangroves into cultivaed areas in peatlands was only 13.85 hectares per year (Table 15).

Table 13. Activity data peat decomposition deforested area (T_1)

Forest Strata	AD peat decomposition deforested T_1 (ha yr^{-1})	SE (ha yr^{-1})
Primary dryland forest	320.68	21.33
Secondary dryland forest	4,017.18	267.2
Primary mangrove forest	61.09	4.06
Primary swamp forest	14,086.59	936.95
Secondary mangrove forest	350.75	23.33
Secondary swamp forest	135,293.99	8,998.90
Total	154,130.28	10,251.77

Table 14. Activity data peat decomposition deforested area (T_2)

Strata	AD peat decomposition deforested T_2 (ha yr^{-1})	SE (ha yr^{-1})
Plantation forest	32,207.10	2,142.21
Dry shrub	1,931.99	128.5
Estate crop	59,806.69	3,977.96

Strata	AD peat decomposition deforested T_2 (ha yr^{-1})	SE (ha yr^{-1})
Settlement	60.59	4.03
Bare ground	8,578.31	570.58
Savanna and Grasses	32.43	2.16
Open water	64.37	4.28
Wet shrub	42,706.00	2,840.53
Pure dry agriculture	2,238.37	148.88
Mixed dry agriculture	5,202.01	346
Paddy field	140.48	9.34
Fish pond/aquaculture	29.78	1.98
Port and harbour	4.33	0.29
Transmigration areas		
Mining areas	309.27	20.57
Open swamps	818.56	54.45
Total	154,130.28	10,251.76

Table 15. 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	13.85	0.92
Total	13.85	0.92

6.1.1.3. Activity data for forest fires

The average annual burnt forest in peatlands that led to deforestation between the periods of 2006/2007 to 2019/2020 was about 51.8 thousand hectares annually (Table 16). 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, which led to deforestation over the reference period was 112,132 ha yr^{-1}. Fires mainly occurred in secondary swamp forests (60%), and secondary dryland forests (33%) (Table 17).

Table 16. Burnt peat forests

Activity	AD peat fire (ha yr^{-1})	SE (ha yr^{-1})
Peat fire	51,782.72	3,444.26

Table 17. 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	2,371.40	157.73
Secondary dryland forest	37,219.73	2,475.62
Primary mangrove forest	167.56	11.14
Primary swamp forest	4,812.70	320.11
Secondary swamp forest	603.15	40.12
Secondary swamp forest	66,958.45	4,453.65
Total	112,132.99	7,458.37

6.1.1.4. Activity data for mangrove conversion

The conversion of mangroves into mineral soils occured over a larger area than the conversion of mangrove into peat soils. The average annual conversion rate for mangroves on mineral soils was 11,483 ha $year^{-1}$. The post-conversion land use area is approximately the same value for both fishpond and cultivation areas. Conversion to fishponds was slightly higher (53%), compared to conversion of mangroves to cultivated land (47%).

Table 18. Activity data on mangrove conversion

Activity	AD mangrove soil (ha yr^{-1})	SE (ha yr^{-1})
Mangrove converted to fish pond	6,046.25	402.16
Mangrove converted to cultivated land	5,436.34	361.59
Total	11,482.59	763.75

6.1.2. Forest degradation

6.1.2.1. Activity data for biomass loss

The average annual forest degradation in Indonesia between 2006/2007 and 2019/2020 was about 316.9 thousand hectares. This represents 266,698 ha (84%) of primary to secondary dry forest, and 40,361 ha (13%) of forest degradation of swamp forest. Primary and secondary mangroves account for less forest degradation (3%).

Table 19. Activity data forest degradation (natural forest)

Activity	AD forest degradation: natural forest (ha yr^{-1})	SE (ha yr^{-1})
Primary dryland forest – secondary dryland forest	266,697.92	44,653.35
Primary mangrove forest – secondary mangrove forest	9,877.35	1,653.77

Activity	AD forest degradation: natural forest (ha yr^{-1})	SE (ha yr^{-1})
Primary swamp forest – secondary swamp forest	40,360.87	6,757.64
Total	316,936.14	53,064.76

6.1.2.2. Activity data for peat decomposition

Average annual forest degradation on peatlands amounted to 17,197 ha yr^{-1}. Aligned with peat decomposition over deforestation, the most degraded forest was swampy forest (87.6%) and the second larget was dry land forest (9.3%), as seen in table below.

Table 20. Activity data forest degradation (peat)

Activity	AD forest degradation: peat (ha yr^{-1})	SE (ha yr^{-1})
Primary dryland forest – secondary dryland forest	1,596.57	267.31
Primary mangrove forest – secondary mangrove forest	530.29	88.79
Primary swamp forest – secondary swamp forest	15,070.20	2,523.21
Total	17,197.06	2,879.31

6.1.2.3. Activity data for forest fires

In forest degradation areas, only 754 hectares were burnt per year. The largest forest fire was link to the degradation of primary dryland forest and primary swamp forest.

Table 21. 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	527.78	88.37
Primary mangrove forest – secondary mangrove forest	18.51	3.1
Primary swamp forest – secondary swamp forest	208.03	34.83
Total	754.32	126.30

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. Whereas the lowest percentage of forest gains or EFCS occurs in port and harbours (0.002%) from total EFCS activities area, which could be part of a land cover classification error. The average annual forest gain area was 353,382 ha yr^{-1}.

Table 22. Activity data initial EFCS (T_1)

Land cover type	AD initial EFCS (T_1) (ha yr^{-1})	SE (ha yr^{-1})
Dry shrub	177,588.37	36,110.28
Estate crop	8,619.79	1,752.72
Settlement	738.34	150.13
Bare ground	23,513.71	4,781.21
Savanna and Grasses	21,468.80	4,365.40
Open water	2,672.70	543.46
Wet shrub	57,834.16	11,759.82
Pure dry agriculture	11,374.87	2,312.93
Mixed dry agriculture	39,017.39	7,933.68
Paddy field	4,708.99	957.51
Fish pond/aquaculture	1,759.06	357.68
Port and harbour	5.83	1.18
Transmigration areas	302.01	61.41
Mining areas	621.28	126.33
Open swamps	3,157.01	641.94
Total	353,382.31	71,855.68

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, which represented only 129 ha or 0.2% of the total forest gain over the reference period.

Table 23. Activity data EFCS – forest (T_2)

Type of Enhance of Forest Carbon Stock	AD – Forest (T_2) (ha yr^{-1})	SE (ha yr^{-1})
Primary dryland forest	14,758.84	3,001.02
Secondary dryland forest	169,332.44	34,431.54
Primary mangrove forest	2,247.49	457
Primary swamp forest	633.94	128.9

Type of Enhance of Forest Carbon Stock	AD – Forest (T_2) (ha yr-1)	SE (ha yr-1)
Secondary mangrove forest	9,460.43	1,923.65
Secondary swamp forest	44,485.28	9,045.50
Plantation forest	112,463.92	22,868.07
Total	353,382.34	71,855.68

6.1.3.2. Activity data for peat decomposition

EFCS activities also took place in peat soil, as presented in table below, with average annual rate of 48,274 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, varies from 0.3 ha to 1,554 ha.

Table 24. Initial land cover class and the activity data of EFCS in peatland (T1)

Land cover type	AD Peat (T_1) (ha yr^{-1})	SE (ha yr^{-1})
Dry shrub	2,407.33	489.50
Estate crop	1,554.12	316.01
Settlement	14.58	2.96
Bare ground	11,426.28	2,323.39
Savanna and Grasses	451.80	91.87
Open water	201.21	40.91
Wet shrub	29,864.32	6,072.52
Pure dry agriculture	132.74	26.99
Mixed dry agriculture	311.77	63.39
Paddy field	2.95	0.60
Fish pond/aquaculture	3.17	0.64
Port and harbour		
Transmigration areas	0.31	0.06
Mining areas	20.15	4.10
Open swamps	1,884.23	383.13
Total	48,274.96	9,816.08

EFCS activities on peatlands showed that most of the EFCS area was afforested/reforested into plantation forest (74%), and secondary swamp forest (22.5%). The other forest strata were relatively few, ranging in size from 5 ha to 162 ha, or less than 2% of the total reforested area.

Table 25. Post-conversion forest types and the activity data on EFCS in peatland (T_2)

Type of Enhancement of Forest Carbon Stock	AD peat - forest (T_2) (ha yr^{-1})	SE (ha yr^{-1})
Primary dryland forest	26.39	5.37
Secondary dryland forest	800.62	162.80
Primary mangrove forest	46.02	9.36
Primary swamp forest	262.98	53.47
Secondary mangrove forest	535.54	108.90
Secondary swamp forest	10,860.10	2,208.26
Plantation forest	35,743.31	7,267.94
Total	48,274.96	9,816.08

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 in the period 2006 to 2020 were approximately 264.3 million tCO_2e annually. Total carbon stock that was deforested in the reference period was 342.5 million tCO_2e annually. The largest biomass emissions from deforestation were mostly from secondary dryland forest and secondary swamp forests, with the initial carbon stock of 205.9 million tCO_2e and 95.0 million tCO_2e, respectively. Total post-conversion carbon stock was 78.2 million tCO_2e, which mostly stored in estate crops, dry shrubs, mixed agriculture and forest plantations.

Table 26. Forest carbon stock before deforestation (T_1)

Forest Strata	C Stock (tCO_2e yr^{-1})	SE (tCO_2e yr^{-1})
Primary dryland forest	24,190,824.71	1,761,986.20
Secondary dryland forest	205,850,039.19	14,953,139.85
Primary mangrove forest	2,058,389.05	181,992.00
Primary swamp forest	11,359,015.88	956,031.33
Secondary mangrove forest	4,089,976.77	572,840.75
Secondary swamp forest	94,994,799.81	7,097,343.16
C Stock T_1	**342,543,045.42**	**16,683,780.45**

Table 27. Post-conversion carbon stock after deforestation (T_2)

Strata	C Stock (tCO_2e yr^{-1})	SE (tCO_2e yr^{-1})
Plantation forest	13,099,754.72	1,396,575.49

Strata	C Stock ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Dry shrub	18,866,925.43	2,313,636.23
Estate crop	23,550,727.13	3,168,900.07
Settlement	26,112.26	11,502.63
Bare ground	158,056.48	75,190.47
Savanna and Grasses	98,714.21	39,861.17
Open water	-	-
Wet shrub	3,449,495.81	638,211.06
Pure dry agriculture	650,042.02	305,735.05
Mixed dry agriculture	18,234,393.13	1,421,217.17
Paddy field	101,621.62	33,607.30
Fish pond/aquaculture	-	-
Port and harbour	-	-
Transmigration areas	12,299.13	3,035.94
Mining areas	-	-
Open swamps	-	-
C Stock T_2	78,248,141.93	4,458,073.84
Net Emissions from Deforestation ($T_1 - T_2$)	264,294,903.49	17,269,132.94

6.2.1.2. Emissions from peat decomposition

Annual emissions from peat decomposition on deforestation area with peat soil was 6.0 million tCO_2. Annual emission level in the initial and the last year of the reference period were 4.5 million tCO_2 and 7.5 tCO_2, respectively. In addition, peat decomposition due to deforestation occurred also where mangrove on peatsoil converted into cultivation, which accounted for only 1.0 thousand tCO_2e annually.

Table 28. Emission peat decomposition of the initial baseline year on deforested areas (T_1)

Forest Strata	Emission Peat Decomposition Deforested T_1 ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Primary dryland forest	-	-
Secondary dryland forest	130,237.01	17,238.36
Primary mangrove forest	-	-
Primary swamp forest	-	-
Secondary mangrove forest	11,371.16	1,505.10
Secondary swamp forest	4,386,231.08	580,567.99
Emission peat decomposition all strata T_1	**4,527,839.25**	**580,825.81**

Table 29. Emission peat decomposition of latest baseline year on deforested areas (T_2)

Strata	Emission peat decomposition deforested T_2 ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Plantation forest	2,349,507.73	366,116.89
Dry shrub	87,016.74	17,320.91
Estate crop	2,190,718.95	302,893.70
Settlement	2,728.87	543.19
Bare ground	547,210.64	46,109.74
Savanna and Grasses	1,460.51	290.72
Open water	-	-
Wet shrub	1,923,478.45	382,873.49
Pure dry agriculture	101,666.93	20,360.98
Mixed dry agriculture	284,341.99	49,194.30
Paddy field	4,735.45	1,552.25
Fish pond/aquaculture	-	-
Port and harbor	-	-
Transmigration areas		
Mining areas	19,728.41	1,662.38
Open swamps	-	-
Emission peat decomposition all strata T_2	**7,512,594.66**	**614,527.95**
Emissions-Peat Dec per year (T_2+T_1)/2	**6,020,216.96**	**845,578.63**

Table 30. Emission from mangrove conversion to cultivated land on peat soil

Forest Strata	Emissions Mangrove – Cultivated In Peat ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Mangrove conversion into cultivation on peatlands	1,010.34	157.44
Total	1,010.34	157.44

6.2.1.3. Emissions from forest fires

Average total emissions from burnt peat soil were 26.4 million tCO_2e annually, which was dominated by emissions from CO_2 (23.8 million $tCO_2\ yr^{-1}$). While emissions from CH_4 only 2.5 million $tCO_2\ yr^{-1}$ (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	23,821,393.62	4,982,719.99
Emission : Peat Fire CH_4	2,536,994.89	632,181.72
Total emission peat Fire	**26,358,388.51**	**5,022,663.85**

Loss of natural forest 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 fire was 2,276,679 tCO_2e yr^{-1}. Meanwhile, average annual N_2O emission from fire was 988,474 tCO_2e yr^{-1}. The largest emission comes from fishpond/aquaculture and estate crop for both gases, as seen in Table 32 and Table 33.

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	42,959.35	13,017.65
Secondary dry land Forest	804,029.32	243,574.68
Primary Mangrove Forest	2,152.29	664.81
Primary Swamp Forest	73,637.57	22,532.24
Secondary Mangrove Forest	6,272.87	2,041.96
Secondary Swamp Forest	1,347,628.27	408,907.19
CH_4 Emissions	2,276,679.67	476,671.26

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	18,651.82	1,756.19
Secondary dry land Forest	349,088.36	31,688.35
Primary Mangrove Forest	934.47	143.60
Primary Swamp Forest	31,971.49	4,336.16
Secondary Mangrove Forest	2,723.52	566.50
Secondary Swamp Forest	585,104.71	61,644.47
N_2O Emissions	988,474.37	69,472.44

6.2.1.4. Emissions from mangrove conversion

Emissons from mangrove conversion during reference period were accounted for 544,541 tCO_2e yr^{-1} from conversion to fishponds and 154,172 tCO_2e yr^{-1} from conversion to other cultivated lands, totalling 698,712 tCO_2e yr^{-1}.

Table 34. Emission: mangrove soil

Activity	Emission: Mangrove Soil (tCO_2e yr^{-1})	SE (tCO_2e yr^{-1})
Mangrove converted to fish pond	544,540.76	142,638.02
Mangrove converted to cultivated land	154,171.64	32,292.82
Mangrove soil emissions	**698,712.40**	**146,247.84**

6.2.2. Emissions from forest degradation

6.2.2.1. Biomass emissions

The average annual historical emission from AGB due to forest degradation in the period 2006/2007 – 2019/2020 amount to approximately 52.8 $MtCO_2e$ yr^{-1} (*see* Table 35**Error! Reference source not found.**). About 98% (51.7 $MtCO_2e$ yr^{-1}) of this figure was accounted for by emissions from primary dryland forest degradation. Meanwhile, forest degradation on peatland emitted approximately 278.8 thousand 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	51,666,593.22	6,225,813.30
Primary mangrove forest – secondary mangrove forest	507,371.87	69,161.82
Primary swamp forest – secondary swamp forest	627,776.39	207,412.70
Total emission forest degradatioan - biomass	**52,801,741.48**	**6,229,651.25**

6.2.2.2. Peat decomposition

Average soil emission from peat decomposition on degradation areas was 278.8 million tCO_2e annually. More than 87% of the emissions due to degradation of primary swamp forest into secondary swamp forest (244.3 million tCO_2e yr^{-1}).

Table 36. Emission: Forest Degradation (peat)

Activity	**Emission: Forest Degradation: peat (tCO_2e yr^{-1})**	**SE (tCO_2e yr^{-1})**
Primary dryland forest – secondary dryland forest	25,880.41	7,339.04
Primary mangrove forest – secondary mangrove forest	8,596.03	2,437.62
Primary swamp forest – secondary swamp forest	244,287.98	69,274.02
Total Emission forest degradation - peat dec	**278,764.42**	**69,704.33**

6.2.2.3. Emissions from biomass burning

The average total emissions from biomass burning that led to forest degradation was 18,618 tCO_2e annually, which consist of CH_4 emission of 12,981 tCO_2e yr^{-1} and N_2O emission of 5,636 tCO_2e yr^{-1}. The largest emission comes from degradation of primary dry land forest for both gases, as seen in Table Table 3637 andTable 38.

Table 37. Emission Non-CO_2 from fire (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	9,560.96	3,248.36
Primary mangrove forest – secondary mangrove forest	237.71	82.01
Primary swamp forest – secondary swamp forest	3,183.07	1,089.88
Total emission CH_4 - fire	**12,981.74**	**3,427.30**

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	4,151.12	748.06
Primary mangrove forest – secondary mangrove forest	103.21	22.43
Primary swamp forest – secondary swamp forest	1,382.00	283.24
Total emission N_2O - fire	**5,636.33**	**800.20**

6.2.3. Removals from ECS

6.2.3.1. Biomass removal

The average biomass removal from EFCS activities in the period 2006 to 2020 was approximately 96.5 million $tCO_2e\ yr^{-1}$. The removal was derived from deduction of the last year period (T_2) carbon stock, i.e. 128.7 million $tCO_2e\ yr^{-1}$ with the initial (T_1) carbon stock, i.e. 32.1 million $tCO_2e\ yr^{-1}$.

Table 39. Initial carbon stock before forest gain (T_1)

Land cover type	Initial stock (T_1) ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Dry shrub	22,843,714.23	5,207,152.97
Estate crop	946,807.58	222,101.08
Settlement	3,556.39	1,709.17
Bare ground	120,204.36	61,672.03
Savanna and Grasses	185,798.59	83,087.37
Open water	-	-
Wet shrub	2,382,661.56	635,562.08
Pure dry agriculture	331,148.42	168,245.98
Mixed dry agriculture	5,215,387.35	1,081,444.69
Paddy field	100,289.01	38,358.56
Fish pond/aquaculture	-	-
Port and harbour	-	-

Land cover type	Initial stock (T_1) ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Transmigration areas	8,792.11	2,750.30
Mining areas	-	-
Open swamps	-	-
Total initial CS (T_1)	**32,138,359.61**	**5,364,487.70**

Table 40. Forest carbon stock of the last period (T_2)

Type of Enhance of Forest Carbon Stock	Potential Stock - Forest (T_2) ($tCO_2e\ yr^{-1}$)	SE ($tCO_2e\ yr^{-1}$)
Primary dryland forest	9,555,768.08	1,963,636.42
Secondary dryland forest	76,831,842.95	15,783,017.32
Primary mangrove forest	1,199,208.92	253,651.88
Primary swamp forest	331,603.32	69,562.12
Secondary mangrove forest	2,145,434.07	510,137.83
Secondary swamp forest	19,136,975.71	3,945,368.46
Plantation forest	19,459,691.41	4,276,163.16
Total potential CS (T_2)	**128,660,524.45**	**16,945,218.39**
Enhance of forest carbon stock Nett (T_1-T_2)	**(96,522,164.84)**	**17,774,086.60**

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 2.6 million tCO_2e annually.

Table 41. Emission from peat decomposition in the EFCS areas

Type of emissions	Emission (ha yr^{-1})	SE ($tCO_2e\ yr^{-1}$)
Total emission at T_1	2,283,517.51	403,746.20
Total emission at T_2	3,002,876.95	650,324.93
Peat Decomposition Emission (T_1+T_2)/2	**2,643,197.23**	**765,462.94**

6.3. Uncertainty Analysis

Based on the uncertainty calculation using the Monte Carlo simulation, we found that overall average emissions were 269.7 million tCO_2e with the lower and upper 95% confidence levels of 218.9 million tCO_2e and 321.2 million tCO_2e, respectively. The overall uncertainty of the emission estimate was 19.1%. The greatest source of uncertainty was the decomposition of peat in forest degradation areas, with uncertainty of 49%. The greatest precision has been the estimated biomass emissions from deforestation with just 12% uncertainty, thanks to the high accuracy of activity data and the high tier data of biomass stock measurement.

Table 42. 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	264,063,461	16,114,387	232,212,592	295,908,276	0.12
Peat decomposition emission (deforestation)	8,288,818	671,269	7,017,079	9,672,053	0.16
Peat fire emission (deforestation)	26,432,988	5,077,523	16,594,810	36,679,599	0.38
Fire emission from biomass and DOM(deforestation)	3,250,471	488,168	2,311,611	4,238,325	0.30
Mangrove soil emissions (deforestation)	702,544	146,518	419,376	993,924	0.41
Biomass emission from forest degradation	58,511,511	9,140,301	40,678,126	76,496,455	0.31
Peat decomposition emission (forest degradation)	278,322	70,590	152,970	429,706	0.50
Fire emission from biomass and DOM (forest degradation)	18,651	3,879	11,779	26,963	0.41
Biomass removal from enhancement of forest carbon stock (EFCS)	(96,486,840)	17,743,408	(130,981,521)	(61,226,197)	(0.36)
Peat decomposition emission (EFCS)	2,645,976	384,804	1,945,141	3,441,575	0.28
Total emissions from deforestation, forest degradation and EFCS	**267,705,902**	**26,199,813**	**216,706,066**	**319,114,918**	**0.19**

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 267.7 $MtCO_2\ yr^{-1}$. Biomass emission from deforestation is the biggest contributor and accounts for 57.3% of the total emissions, equivalent to 264.1 $MtCO_2e$ (Table 42; Figure *3*). Biomass emissions from forest degradation contributed for 12.7% of total emissions at 58.5 $MtCO_2e$.

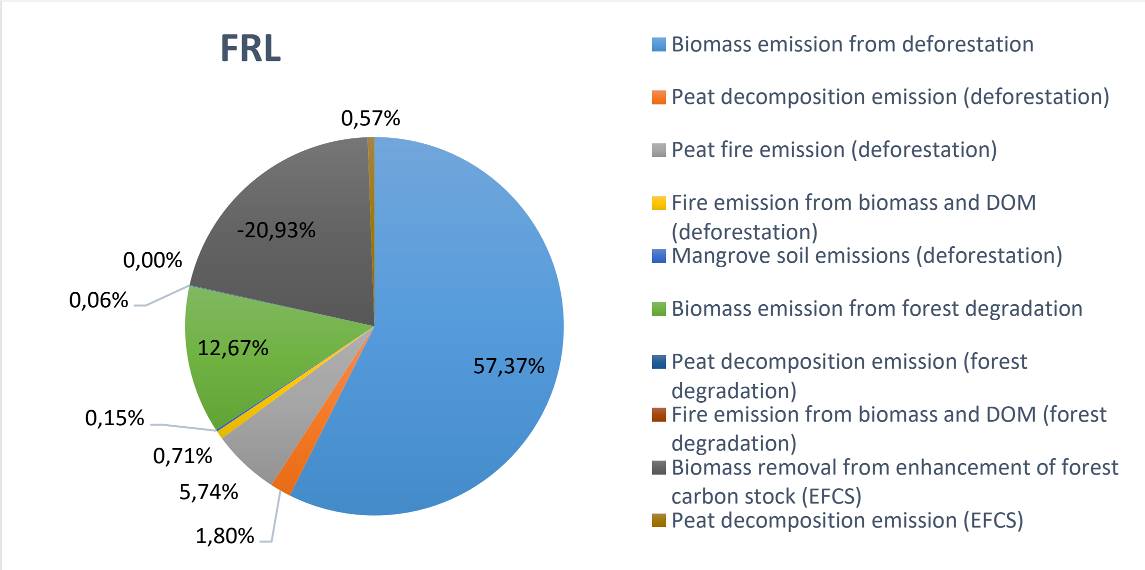

Figure 3. *Annual and average annual historical emissions from deforestation, forest degradation and the associated peat decomposition (in* $MtCO_2$*) in Indonesia from 1990 to 2012*

Compared to the 1st FREL, emissions from peat decomposition in this submission are much less due to the exclusion of inherited emissions. Total emission from peat decomposition was only 11.2 $MtCO_2\ yr^{-1}$, compared to about 226 $MtCO_2\ yr^{-1}$ in the 1st FREL. Emissions from peat decomposition included in this calculation are emissions that are directly associated with deforestation, forest degradation and enhancement of forest carbon stock. Similarly, an insignificant emission from mangrove soil and biomass burning represents only less than 1% of total emissions.

The new and significant activities included in this submission have been enhanced for forest carbon stocks and peat fires. The absolute contribution from the elimination of enhancement of forest carbon stock was the 2nd largest after biomass emissions from deforestation with a contribution of -20.8% or -96.8 $MtCO_2e$. Emissions from peat fires not included in the 1st FREL represent over 5% of the total emissions.

This calculation followed the guidelines and conforms to the standard established by the COP decision, including the TACC of data. The constructed FRL serves as the basis for assessing emission reductions resulting from post 2020 REDD+ activities. The reference level are based on the 14 years of historical emissions and will be projected in 5 to 10 years.

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

Forest restoration and rehabilitation has been one of important effort to achieve national commitment in reducing GHG emission through enhancement of forest carbon stock. Forestry Law number 41/1999 stated that the objective of rehabilitation is to restore, to protect and improve the carrying capacity, productivity, and roles in environmental services of the degraded lands. Currently there are about 30 million hectare unproductive land, out of which 7.7 million hectares are heavily degraded (MoEF, 2021). Indonesia is aiming at accelerating restoring degraded land for protecting environmental services (KLHK, 2019). In addition, acceleration the establishment of forest plantation in unproductive land to meet the increasing wood demand and reduce pressure to natural forest, has also been put into a priority. Also, expansion of mandate of National Agency for Peat Restoration (BRG) to include mangrove so that it becomes National Agency for Peat and Mangrove Restoration (BRGM) suggest that the restoration of degraded peatland and mangrove 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. Therefore, enhancement of forest carbon stock has been included in the FRL.

Conversion of peat forest and mangrove which is rich with soil carbon will contribute significantly to GHG emissions. Specific regulations on wetland management have been enacted to protect the carbon-rich ecosystem (e.g. MoEF regulation number 15/2017 that reinforces water management of peatland in concessionaires; MoEF Regulation No.P.16/2017 that guide to restoring peat ecosystem functions). During prolonged dry season, drained peatlands are susceptible to fires, which consume organic soils and release large amount of GHG emissions. Controlling land and forest fire has been mandated by the government to all land managers through a number of 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). Failing in controlling the fire may expose to sanctions. The presence of these policies, the FRL also includes emissions from peat decomposition and peat fires and non-CO2 emissions from biomass burning.

8. Opportunities for Improvement

The FREL was developed based on the data and knowledge currently available in national circumstances, capacities and capabilities.The limitation of the analysis were 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 better methodology become available, noting the importance of appropriate and predictable support as referred to inparagraph 71 of Decision 1/CP.16.

Several aspects of potential improvement were identified, including the inclusion of additional REDD+ activities, improved acuracy of emission factor, and improved activity data (Table 43). Other REDD+ activities not included in the submission are sustainable forest management 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 ensure that none of them account for the same emissions, for example, monitoring of forest degradation may overlap with monitoring of sustainable forest management. A more detailed emission factor and high-resolution activity data may be able to explore additionality of emission reductions that do not overlap.

Table 43. 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	Compilation of new studies
EF improvement	• Tier 2 of EF for mangrove conversion to cultivation • Removal factors of rehabilitation efforts • Peat depth fires absed on fire frequency • EF and baseline for peat rewetting activity	Compilation of new studies
AD improvement	• AD for ECS in degraded forests • Rewetting of peatlands could have a significant impact on emission reduction and the	New methods based on remote sensing that can monitor specific changes over a large surface area

Type of Improvement	Plan of Improvement	Requirement or Challenges
	mapping of large-scale reading AD mapping	

Improvement in the accuracy of emission factors is expected to be one of the prioritised plan of activities. Given that most of the emissions from peatlands were based on IPCC default values, the revision of the emission factors through the compilation and promotion of new relevant studies should be highly rewarded and contribute significantly to the accuracy of the overal estimates.

The inclusion of other carbon pools and gases is considered a good strategy to be consistent with the principle of completeness. Dead organic matter is still excluded from the assessment of biomass emissions associated with deforestation and forest degradation. Other non- CO_2 gases as a result of peat decomposition, such as CH_4 and N_2O, could easily 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 1990s, for land cover mapping of Indonesia. The mapping system was first established in 2000 and was initially be updated every three years based on data availability, due to problems of clouds and haze, and cost-effectiveness. In total, 217 Landsat scenes are required to cover the entire land area of Indonesia, excluding additional scenes to minimise/remove clouds and the presence of haze. Until 2006, other data sets such as SPOT Vegetation 1000 metres and MODIS 250 metres 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 that has 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 2000, 2003, 2006, 2009, 2011, 2012, 2013, 2014 and 2015.Over the past five years, efforts have been made to update land cover data from the 1990s, to renew the information gathered during the era of NFI. However, the USGS and LAPAN do not have enough archived Landsat scenes, so the annual 1990s mapping was not possible; thus only two datasets for the 1990s were established, i.e. 1990 and 1996.

To maintain product continuity and further improve the work, a collaboration between LAPAN for Landsat data preparation and MoFor/MoEF for the classification process is a significant key for future works. Both institutions have a Memorandum of Understanding on the work since 2004 which was recently updated. The existing system is known as the NFMS or Simontana (*Sistem Monitoring Hutan Nasional*) (MoFor, 2014). It is available online at http://nfms.dephut.go.id/ipsdh/, coupled with a webGIS at http://webgis.dephut.go.id/ for display and viewing or the updated web version at http://webgis.dephut.go.id:8080/klhk/home/mapview. 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.

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 (MoF, 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	Class	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 lime-stone, 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 lime-stone, 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.
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).
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 fish ponds, 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.
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 metre spatial resolution). The class names (**Error! Reference source not found.**) correspond 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 digitising technique based on key elements of image/photo-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.

Annual forest cover from period 2006 – 2020 is presented in Table Annex 1.2. Forest cover is declining from 94.9 million hectare in 2006 to 89.6 million hectare in 2020. The largest forest cover extends mostly in Papua and Kalimantan islands, with 36.5 million hectares and 27.1 million hectares in 2020, respectively. Sumatra and Kalimantan experience more forest loss than any other islands in Indonesia with total forest loss more than 2 million hectares from 2006 to 2020. Other islands are relatively stable with small amount of nett forest loss. However, only Papua Island that has net forest gain from 36.2 million hectares in 2006 to 36.5 million hectares in 2020.

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

Islands/Forest Land	2006	2009	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
A. SUMATERA	**15,983,084.3**	**14,707,984.7**	**14,580,456.8**	**14,293,723.5**	**14,102,392.0**	**13,874,245.5**	**13,335,788.6**	**13,241,446.2**	**13,089,037.2**	**13,814,705.5**	**13,980,242.3**	**13,962,176.0**
- Primary dry land Forest	4,082,604.3	4,070,960.3	4,038,825.1	4,031,567.0	4,022,643.5	4,013,168.2	3,984,106.1	4,706,618.6	4,754,395.8	4,757,240.6	4,967,755.7	4,966,243.8
- Secondary dry land Forest	7,083,333.6	6,337,494.8	6,191,391.3	5,986,712.3	5,788,238.7	5,729,004.7	5,650,451.0	4,863,595.3	4,709,464.6	4,655,897.2	4,439,161.2	4,431,403.2
- Primary Mangrove Forest	191,728.8	162,183.1	159,200.9	158,491.8	157,737.8	157,733.3	143,040.1	140,257.5	137,374.2	136,808.3	128,209.1	128,042.7
- Primary Swamp Forest	479,261.0	341,623.4	312,674.6	304,499.8	283,977.2	282,452.7	270,418.0	228,245.4	227,035.7	207,272.1	247,764.8	245,603.6
- Secondary Mangrove Forest	401,506.3	405,126.7	409,827.7	404,330.9	402,958.7	401,242.4	407,425.3	423,625.5	426,087.4	415,431.5	446,547.9	445,731.5
- Secondary Swamp Forest	2,669,473.7	2,071,873.6	1,818,134.3	1,679,107.6	1,595,002.7	1,497,354.3	1,421,390.6	1,418,092.6	1,375,305.5	1,334,103.8	1,287,146.3	1,278,984.1
- Plantation forest	1,075,176.7	1,318,722.7	1,650,402.8	1,729,014.0	1,851,833.4	1,793,289.9	1,458,957.5	1,461,011.4	1,459,374.1	2,307,952.1	2,463,657.2	2,466,167.0
B. KALIMANTAN	**29,820,715.7**	**28,802,485.2**	**28,374,946.5**	**28,065,440.2**	**27,622,464.1**	**27,488,259.8**	**27,110,560.8**	**26,747,333.1**	**26,516,300.8**	**26,651,749.4**	**27,162,471.0**	**27,120,957.9**
- Primary dry land Forest	9,768,913.8	9,698,452.0	9,680,185.7	9,666,037.8	9,649,507.1	9,611,125.7	9,463,690.0	9,411,699.6	9,483,955.9	9,357,911.9	9,391,075.9	9,390,935.3
- Secondary dry land Forest	14,357,979.2	13,835,181.9	13,582,303.6	13,394,967.6	13,139,325.5	13,064,887.0	13,092,360.2	12,923,055.9	12,656,137.9	12,734,209.9	13,021,015.8	13,000,981.0
- Primary Mangrove Forest	63,528.7	61,447.0	61,101.0	60,946.9	60,068.4	59,540.3	59,185.6	57,511.9	52,401.0	75,164.4	72,128.7	71,947.0
- Primary Swamp Forest	116,136.5	108,316.3	105,945.5	105,005.8	99,018.0	97,142.4	75,114.5	75,592.3	73,255.5	68,426.3	61,064.7	61,043.2
- Secondary Mangrove Forest	481,180.1	464,555.9	462,174.0	453,315.0	448,482.2	445,904.8	449,647.4	423,569.1	427,353.1	404,435.8	433,321.2	432,223.5
- Secondary Swamp Forest	4,402,320.1	3,971,754.3	3,813,920.3	3,736,916.5	3,537,695.6	3,497,394.6	3,287,921.5	3,149,737.7	3,112,309.8	3,056,388.5	3,154,158.4	3,134,822.7
- Plantation forest	630,657.3	662,777.7	669,316.4	648,250.8	688,367.2	712,265.0	682,641.6	706,166.6	710,887.6	955,212.6	1,029,706.2	1,029,005.2
C. SULAWESI	**9,675,775.7**	**9,540,592.1**	**9,464,851.4**	**9,449,141.5**	**9,404,378.9**	**9,386,641.7**	**9,329,278.0**	**9,244,138.2**	**9,172,981.1**	**9,140,329.8**	**9,240,984.8**	**9,225,678.0**
- Primary dry land Forest	4,172,344.5	4,073,875.3	3,869,180.8	3,856,830.7	3,841,022.3	3,836,043.1	3,767,190.2	3,832,378.5	3,920,973.7	5,026,426.4	5,055,631.3	4,725,846.8
- Secondary dry land Forest	5,284,628.7	5,262,866.4	5,392,460.8	5,387,345.9	5,359,361.2	5,347,810.8	5,361,669.0	5,215,766.8	5,064,850.3	3,932,927.2	3,987,890.5	4,300,303.1
- Primary Mangrove Forest	41,237.0	39,257.9	39,050.6	39,050.6	38,988.7	37,341.1	36,066.1	35,470.1	34,901.5	34,320.9	35,419.9	35,384.0
- Primary Swamp Forest	755.6	755.6	755.6	755.6	755.6	755.6	315.7	641.2	637.9	607.3	51.2	51.2
- Secondary Mangrove Forest	135,261.5	133,703.2	133,284.3	133,100.0	132,174.0	132,818.5	131,841.3	127,882.9	124,502.5	111,295.7	111,725.4	111,095.2
- Secondary Swamp Forest	25,260.6	14,021.9	13,944.3	13,879.6	13,903.7	13,566.7	14,233.1	13,468.6	11,833.1	9,462.0	14,249.8	14,147.2
- Plantation forest	16,287.7	16,111.9	16,175.0	18,179.1	18,173.5	18,305.9	17,962.6	18,530.1	15,282.2	25,290.4	36,016.7	38,850.5
D. PAPUA	**36,217,224.8**	**36,102,896.2**	**36,071,082.9**	**36,042,483.7**	**36,018,659.1**	**35,996,351.1**	**35,915,240.3**	**35,899,138.6**	**35,850,676.5**	**36,140,078.8**	**36,490,741.5**	**36,482,193.9**
- Primary dry land Forest	23,049,895.9	22,219,569.9	22,166,700.3	22,162,540.0	22,015,216.2	21,979,583.2	21,700,539.0	21,564,149.4	21,489,177.9	21,420,341.4	21,431,594.7	21,392,126.7
- Secondary dry land Forest	5,549,866.1	6,292,297.0	6,319,537.5	6,300,079.8	6,426,930.8	6,444,557.0	6,661,845.4	6,791,977.5	6,819,092.3	6,425,495.1	6,466,264.7	6,498,159.8
- Primary Mangrove Forest	1,123,211.0	1,114,663.1	1,114,268.9	1,114,700.9	1,108,110.6	1,104,748.3	1,102,532.3	1,098,923.2	1,099,813.0	1,111,193.1	1,199,616.0	1,197,529.2
- Primary Swamp Forest	5,191,093.2	5,028,236.9	4,999,814.3	4,997,680.6	4,977,289.0	4,955,298.7	4,946,662.9	4,920,923.6	4,912,051.5	4,751,433.9	4,565,643.0	4,560,711.9
- Secondary Mangrove Forest	192,309.0	199,868.8	199,859.8	199,656.6	206,130.3	208,862.8	209,817.1	213,177.6	213,389.2	235,130.9	239,688.9	241,597.0
- Secondary Swamp Forest	1,109,017.1	1,246,376.4	1,269,018.3	1,265,941.8	1,283,098.2	1,301,417.1	1,291,964.0	1,308,107.7	1,315,272.9	2,194,897.8	2,585,663.6	2,590,155.7
- Plantation forest	1,832.4	1,884.0	1,884.0	1,884.0	1,884.0	1,884.0	1,879.6	1,879.6	1,879.6	1,586.6	2,270.8	1,913.6
E. BALINUS	**2,859,783.0**	**2,855,296.8**	**2,852,741.0**	**3,035,652.7**	**3,033,066.0**	**3,032,829.0**	**3,009,193.5**	**2,979,426.2**	**2,994,009.7**	**2,816,821.1**	**2,793,520.1**	**2,772,139.7**
- Primary dry land Forest	753,854.0	693,786.5	691,533.8	708,279.5	707,028.3	705,881.9	629,312.1	884,291.7	904,344.4	942,746.8	913,067.8	900,753.1
- Secondary dry land Forest	2,062,839.9	2,118,300.0	2,118,242.2	2,281,773.2	2,280,475.2	2,280,259.2	2,332,866.1	2,051,439.0	2,044,475.8	1,822,801.1	1,826,033.0	1,817,081.4
- Primary Mangrove Forest	20,074.0	20,043.1	19,895.6	19,492.7	19,492.7	19,469.5	18,604.7	16,613.4	15,204.9	13,677.3	13,841.5	13,832.5
- Primary Swamp Forest												
- Secondary Mangrove Forest	17,457.9	17,703.0	17,605.2	19,137.4	19,099.9	19,096.3	19,972.7	20,323.6	21,641.4	22,160.0	22,879.0	22,762.7
- Secondary Swamp Forest	498.9	498.9	498.9	498.9	498.9	498.9	498.9	753.6	753.6	260.8	260.8	260.8
- Plantation forest	5,058.3	4,965.3	4,965.3	6,470.9	6,470.9	7,623.2	7,939.0	6,005.0	7,589.6	15,175.1	17,438.1	17,449.3
F. MALUKU	**5,310,548.5**	**5,286,429.7**	**5,264,932.1**	**5,267,034.0**	**5,260,170.1**	**5,257,706.2**	**5,240,547.0**	**5,208,057.4**	**5,186,644.7**	**5,187,848.9**	**5,254,477.2**	**5,243,217.6**
- Primary dry land Forest	868,594.2	868,229.5	859,122.6	859,112.3	859,102.5	859,061.9	812,735.0	788,197.4	786,742.9	631,960.1	636,502.8	635,914.4
- Secondary dry land Forest	4,115,423.5	4,091,884.0	4,080,537.3	4,080,397.0	4,073,962.2	4,069,973.6	4,097,274.2	4,096,932.4	4,076,819.3	4,145,617.4	4,293,402.5	4,282,739.1
- Primary Mangrove Forest	81,608.2	76,263.6	76,180.8	109,425.7	109,215.0	108,781.6	107,251.9	106,589.5	108,510.8	124,362.9	128,586.4	128,586.4
- Primary Swamp Forest	35,233.5	35,233.5	35,233.5	1,876.8	1,876.8	1,876.8	1,114.3	935.0	723.7	724.7	725.8	725.8
- Secondary Mangrove Forest	109,698.1	114,812.2	114,872.2	152,654.0	152,195.7	152,498.7	154,470.3	156,680.1	155,606.6	227,529.6	137,630.7	137,622.9
- Secondary Swamp Forest	64,834.3	64,923.2	63,902.0	28,484.5	28,734.2	28,484.5	30,672.3	21,990.2	21,520.7	21,230.0	21,225.7	21,225.7
- Plantation forest	35,156.7	35,083.7	35,083.7	35,083.7	35,083.7	37,029.1	37,029.0	36,732.8	36,720.7	36,424.2	36,403.3	36,403.3
G. JAWA	**3,395,827.5**	**3,345,720.8**	**3,344,025.1**	**3,341,892.2**	**3,337,613.8**	**3,345,360.7**	**3,324,347.6**	**3,324,399.6**	**3,330,125.2**	**2,953,710.4**	**2,794,414.5**	**2,794,380.2**
- Primary dry land Forest	296,400.9	22,849.1	22,699.1	22,699.1	22,699.1	22,655.7	21,553.8	63,245.0	63,220.1	61,536.6	61,445.2	61,445.2
- Secondary dry land Forest	524,912.2	792,856.6	787,520.4	786,256.5	783,213.4	770,275.8	767,204.8	766,301.1	749,857.2	772,064.9	794,942.1	794,942.1
- Primary Mangrove Forest	13,398.8	12,471.2	12,471.2	12,471.2	12,471.2	12,471.2	12,471.2	12,377.5	12,164.7	11,849.0	11,922.2	11,922.2
- Primary Swamp Forest	48.2	48.2	48.2	48.2	48.2	48.2	48.2					
- Secondary Mangrove Forest	20,331.6	15,488.6	15,527.1	15,559.3	14,352.3	14,342.2	13,965.5	14,291.6	14,969.9	20,949.0	21,805.7	21,771.4
- Secondary Swamp Forest								14.5	14.5		913.2	913.2
- Plantation forest	2,540,735.7	2,502,007.1	2,505,759.1	2,504,857.8	2,504,829.5	2,525,567.5	2,509,104.1	2,468,169.9	2,489,898.8	2,087,310.9	1,903,386.1	1,903,386.1
Grand Total	**94,852,984.3**	**92,032,104.1**	**91,366,777.6**	**90,909,140.7**	**90,203,659.2**	**89,800,982.8**	**88,721,615.1**	**88,174,727.4**	**87,686,225.3**	**88,625,221.3**	**89,729,405.0**	**89,624,590.6**

Accuracy Assessment of Land Cover Maps

Accuracy assessments of land cover maps of 1990, 1990, 1996, 2000, 2003, 2006, 2009, 2011, 2012, 2013, 2014, 2015, and 2016 were carried out by the Ministry of Environment and Forestry in 2020[3]. 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 the reference points that randomly distributed 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 this analysis were 10,000 sample points, randomly and proportionally distributed to all islands in Indonesia (Table Annex 1.3).

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

Island	Total Area (Million Hectares)	Area Percentages (%)	Sampling Point
Papua	41,581,672	21.75	2,172
Jawa	13,580,683	7.10	702
Kalimantan	53,867,224	28.18	2,828
Maluku	7,889,980	4.13	413
Bali Nusa Tenggara	7,430,680	3.89	381
Sulawesi	18,812,076	9.84	987
Sumatera	47,992,944	25.11	2,517
Total	191,155,260	100.00	10,000

Accuracy was estimated using the error matrix and Kappa (coefficient and accuracy). Observation of land cover data samples (validation) based on a random distribution of 10,000 reference data for all periods of the year measured (1990 to 2016). 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

[3] KLHK. 2020. Akurasi Data Penutupan Lahan Nasional tahun 1990 – 2016. Direktorat Inventarisasi dan Pemantauan Sumber daya Hutan. Ditjen Planologi da Tata Lingkungan. KLHK

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 natural forest (F) and non-natural forest (NF) classes as well as 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 Accuracy	**Producer Accuracy**	**Overall Accuracy**
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
	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

Period Year	Land Cover	Accuracy		
		User Accuracy	Producer Accuracy	Overall Accuracy
	Non Forest	92.5	92.3	
2016	Forest	92.8	90.1	91.9
	Non Forest	91.2	93.6	

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.The land cover data used in this submission are those based on the first refinement.

<u>Other data sets introduced in this report</u>

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, available online since June 2014. The study is part of the global mapping system of Hansen *et al.* (2013) with specific modifications for national scale (Indonesia). The study generates three main land cover classes: primary intact forest, primary degraded forest, and non-primary forest (other land cover). Referring to the supplementary material of the NCC submission, primary forests was defined as all mature forests of 5 ha or more, to an 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 into two types: intact (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 1.3).

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 1.3. 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 simple 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 and change mapping, as well as review of the product. The outputs from one steps are 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 1.4 and Figure Annex 1.1).

Table Annex 1.4. 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

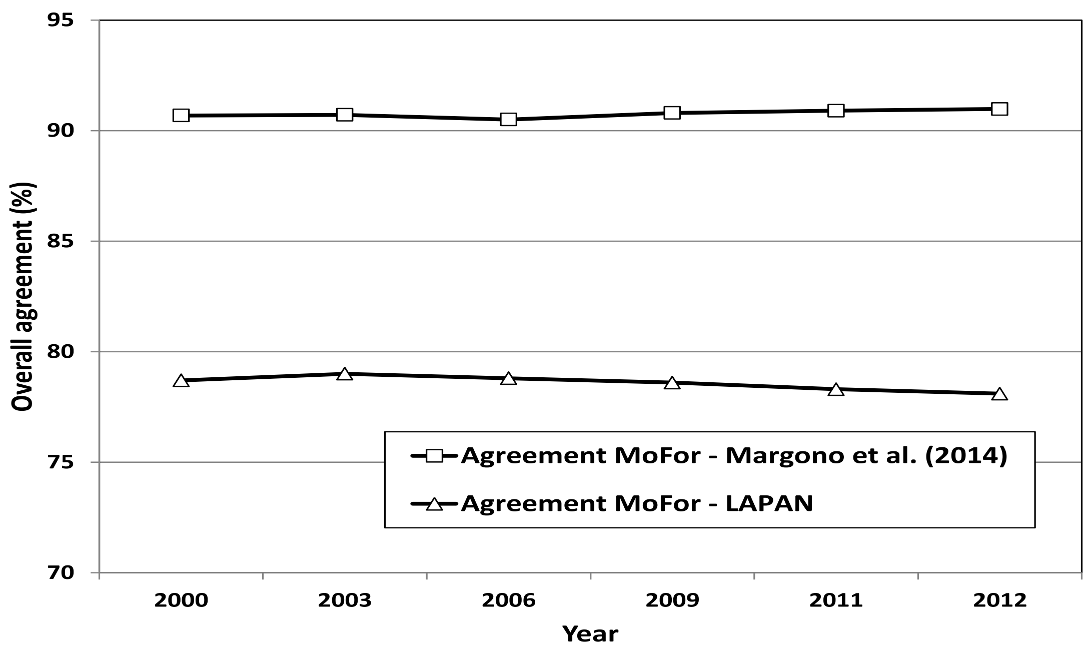

Figure Annex 1.1. Agreement of the MoFor land cover data used in this analysis to the other two independent studies (Margono and LAPAN/LCCA-LAPAN).

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Margono B. A., Potapov P. V., Turubanova S., Fred Stolle F., Matthew Hansen C. M. (2014).*Primary Forest Cover Loss In Indonesia Over 2000–2012*. Nature Climate Change 4, 730–735.

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Annex 2. Peat land data

Peat land mapping activities in Indonesia are closely related to soil mapping projects for agricultural development programmes, 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). The map of Indonesia peat land map has been updated and released several times due to the dynamics of data availability.

For this FREL 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 (BBDSLP) Ministry of Agriculture.

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

The data method to prepare the peat map of Indonesia 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.

[4] Anda, M., Ritung, S., Suryani, E., Hikmat, M., Yatno, E., Mulyani, A. and Subandiono, R.E., 2021. Revisiting tropical peatlands in Indonesia: Semi-detailed mapping, extent and depth distribution assessment. *Geoderma*, *402*, p.115235.

Method:

A comparative method was used. All data collected from any sources were compared spatially by using spatial data analysis tools and combined with 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 the Presidential Instruction (Inpres) No. 10/2011 (forest moratorium) and the Minister of Agriculture Regulation (Permentan) No. 4/2009.

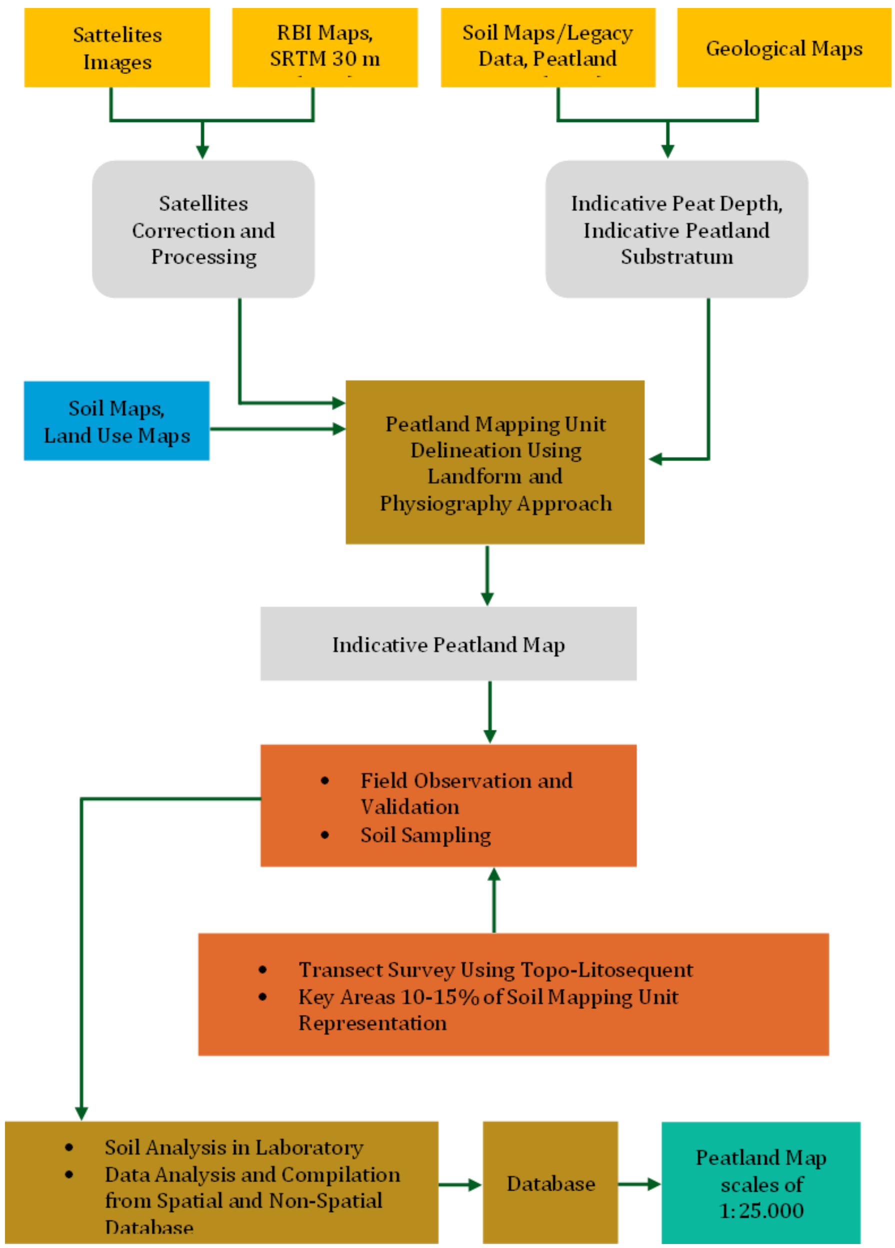


Figure Annex 2.1. Flow chart of peat land mapping procedure

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 peat land area area: wetness (surface drainage), topography, and land cover. Field measurements were conducted to verify the remote sensing analysis results. 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:

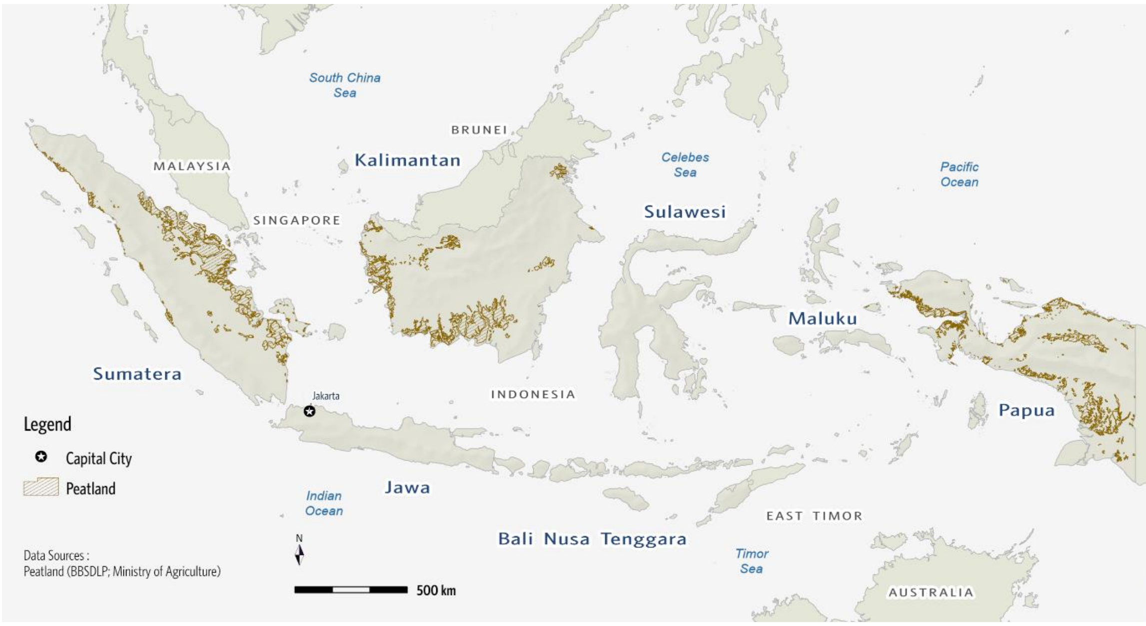
- The density of sample points in ground truth activity
- The variety of soil types
- The quality of the remotely sensed data
- The accuracy of the delineation of the map soil and land unit map.
- The competency of the surveyors.

The present extent of peatland in Indonesia (13.43 million ha) (BBSLDP, 2019) was smaller than previous map (14.91 million ha). The smaller peatland extent in the present semi-detailed mapping inventory than 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 results 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


South China Sea
BRUNEI
MALAYSIA
Kalimantan
Celebes Sea
Pacific Ocean
SINGAPORE
Sulawesi
Maluku
Sumatera
Jakarta
INDONESIA
Papua
Legend
Capital City
Peatland
Indian Ocean
Jawa
EAST TIMOR
Bali Nusa Tenggara
Timor Sea
Data Sources :
Peatland (BBSDLP; Ministry of Agriculture)
N
500 km
AUSTRALIA

Annex 3. Burn area mapping

In the past four decades vegetation fires have become recurrent events in tropical ecosystem including Indonesia (Dennis *et al*, 2001; Nepstad *et al*, 1999). Prolonged dry seasons boosted by El Nino increase risk and intensity of fires, particularly in drained peatlands. In 1982-1983, fires affected approximately to 5 million hectares of forests in Borneo (Leighton and Wirawan, 1986). In 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 (ADB, 1999). The most recent fires hit Indonesia during extreme dry season in 2015 and 2019. More than 2 million hectares of forest and lands were burned during 2015 fires (MoEF, 2021).

As major source of emissions, accurate estimation of burn areas is crucial for assessing national GHG emission level. Robust and standardised method is required to producing burn area maps annually. MoEF has mapped the burn areas based on remote sensing data since 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. Most of 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 type (Figure Annex 3.1). Fires occuring in forest estates were slightly larger than in non forest estates or other land use.

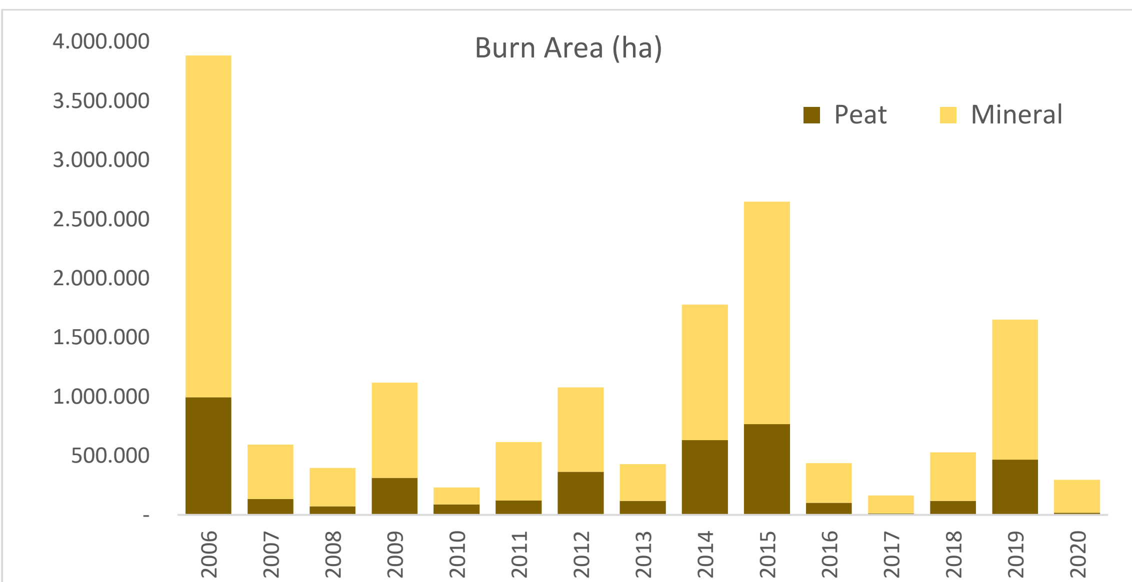


Figure Annex 3.1. Estimates of peat burnt area 2006-2020 (KLHK, 2021)

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. 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 satelite imageries was performed in map scale of 1:25,000 – 1:50,000 to obtain a good resolution of published maps at 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 equivalent to minimum area of 6.25 hectares. The calssification of each burn area polygon will include the deliniation of the polygon with 3 levels of accuracy, *i.e.* high, medium and low. High level accuracy, if within the polygon, satellite imageries, hotspot data and groundthruthing data are confirming that fire occurs in the polygon. While medium level accuracy if only hotspot and burn scars in satellite imageries are detected. When fire detected only in satellite imageries, the polygon will be considered low level accuracy. Procedure for estimating peatburnt area is presented below (Figure Annex 3.2).

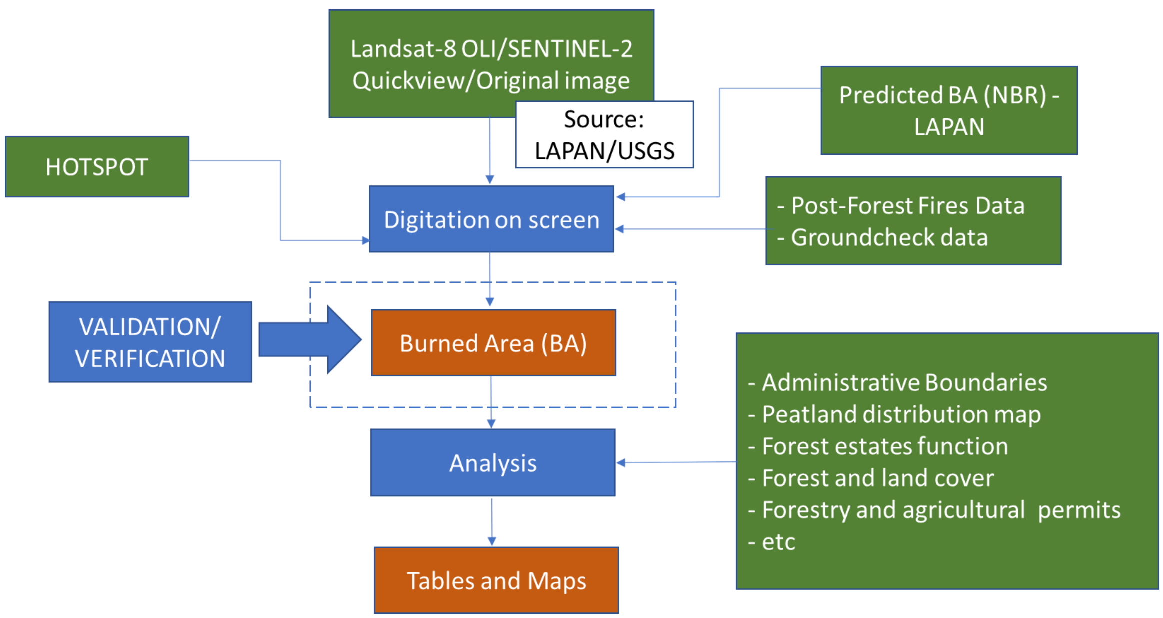


Figure Annex 3.2. Procedure for estimating peat burnt (KLHK, 2021)

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Annex 4. Forest carbon stock data

Background information

NFI was initially a Word Bank and United Nations supported project to assist MoFor in conducting forest resource enumeration during the period of 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 for the purpose of establishing 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 inventory 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 area below 1000 m above sea level. In addition to that, a land and forest cover map was produced at 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 detail 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 programme from the DGFP. Activities related to NFI that is being implemented by DGFP 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 national scale. The NFI plots are actually 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).

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 PSP were established between the 20 km x 20 km grid (i.e. become 10 km x 10 km) in production forests and at altitude above 1000 m ASL. None of the clusters are located outside forestland, even though it is forested.

Since the commencement of the NFI programme in 1989, PSP/TSP that have been established and measured until 2014 totalling 3,928 clusters distributed in seven major islands/regions. 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.

Table Annex 4.1. Cluster distribution of NFI's PSP/TSP

	2014	**2015**	
Islands	**N Clusters**		**%**
Java	92		2.3
Kalimantan	1277		32.5
Maluku	225		5.7
Nusa Tenggara	307		7.8
Papua	540		13.7
Sulawesi	565		14.4
Sumatra	922		23.5
Total	3928		100.0

Parameter being measured

Since the main purpose of NFI was to monitor forest resources, data to generate timber volume or stocks were strongly required. These includes species name (local name), tree DBH or above buttress, tree height and 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 cluster level, general information such as, ecosystem type, forest type, land system, altitude, aspect, slope, terrain and logging history was also recorded. All trees 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.

<u>Post stratification</u>

For the FREL calculation, the land cover categories for each plot were allocated from 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 current land cover categories used for the FREL.

<u>NFI data calculation</u>

For the purpose of FREL, only PSPs data were used for calculation (Tract No. 5). Furthermore, only natural forest classes were included. In total, 4,450 PSP measurements (1990-2013) nationwide were available for data processing and analysis. All the trees in the plot were examined and the plot information was checked for each plot to ensure that the information was accurate 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.

Of the 4,450 measurement data available from NFI PSPs, 80% were located in forested areas while the remainders were located in shrubs or other land cover types.

Using the total number of PSPs measured, the data validation process reduced the useable number of measurement data to 2,622 (74.1%) for further analysis. These selected PSPs were primarilly located in drylands and swamp forest. PSPs located in the mangrove forest were excluded because there were insufficient PSP records available in that forest type.

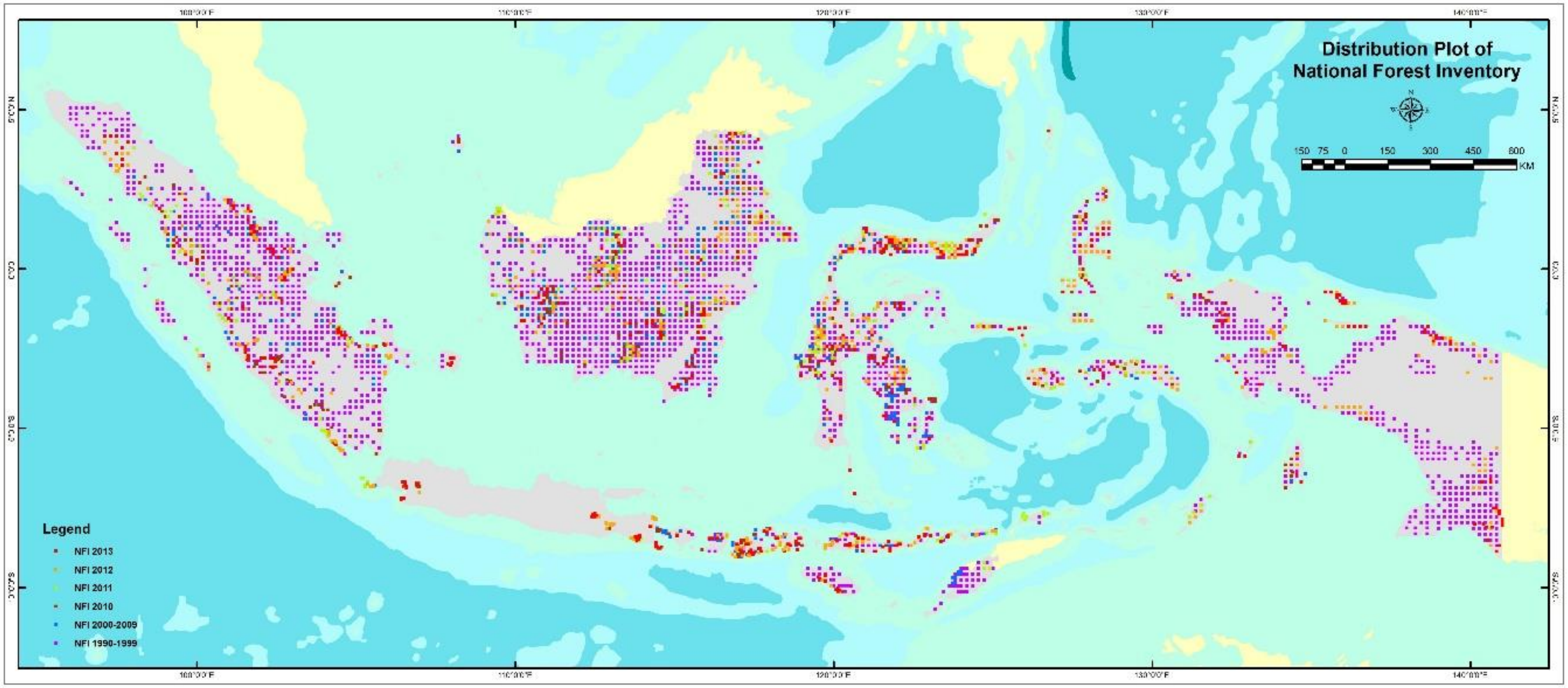

Figure Annex 4.1. NFI's PSP/TSP distribution map.

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

In addition to PSP data, NFI system also provide TSP data, which were collected using 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. We estimate the AGB based on the calculated basal area of each plot. For this purpose, the relationship between basal area ofthe plots and AGB of the plots was developed (see Figure Annex 4.2).

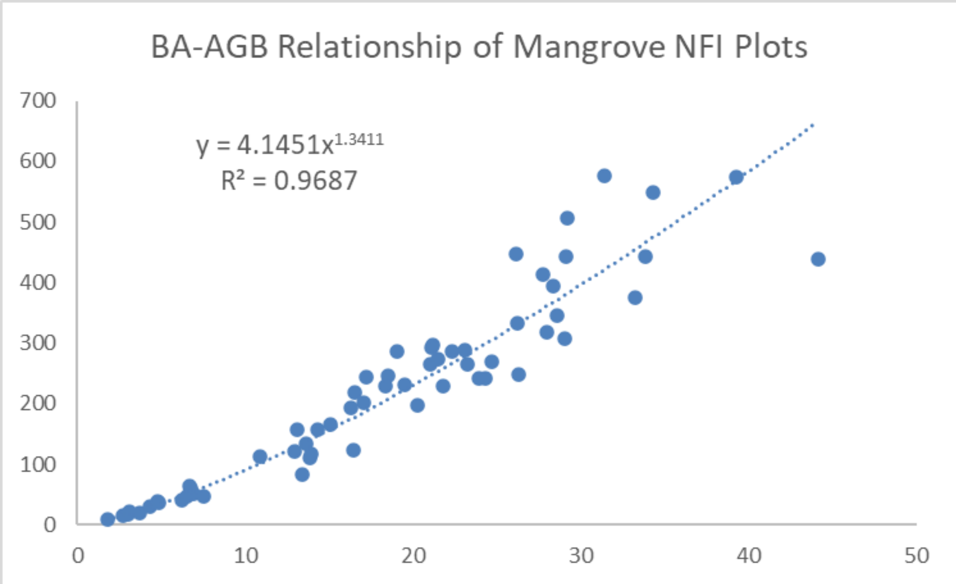

Figure annex 4.2. Scatter plot relationship between basal area and aboveground biomass based on mangrove NFI plot

Selection of Unbiased Allometric Equations

To estimate the total tree biomass, an allometric equation was applied using field measurement data (DBH and tree species). The 2016 FREL used 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 tropcial 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 more accurate and non-biased estimate, than the use of global equations. Therefore, in this submission, the AGB of individual trees in the plots were estimated using allometric model developed for Indonesian forests (Manuri *et al.*, 2017), which used DBH, wood density (WD) of the species and region as the key parameters.

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

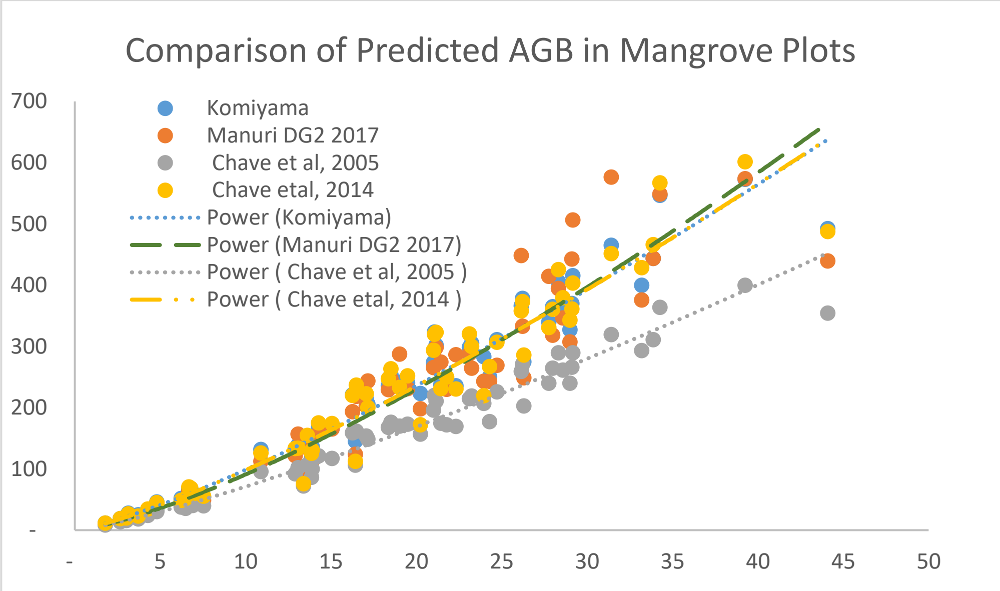

Figure Annex 4.3. Comparison of allometric equations applied to mangrove plots of NFI data

To further analyse for selecton of the best allometric for mangrove forests, we used independent data of unpublished destructive sampling from mangrove forests in South Sumatra. The total numer of samples is 8 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 beter 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 to use 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 $(\text{Ln D})^3$ – 0.0281 $(\text{Ln D})^3$] × ρ
Other forest	Manuri *et al.*, 2017	Sumatera- Kalimantan $AGB=0,167D^{2,560}G^{0,889}$ Jawa – Bali – Nusa Tenggara – Sulawesi - Maluku $AGB=0,151D^{2,560}G^{0,889}$ Papua $AGB=0,206D^{2,560}G^{0,889}$

The WD 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 WD 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.

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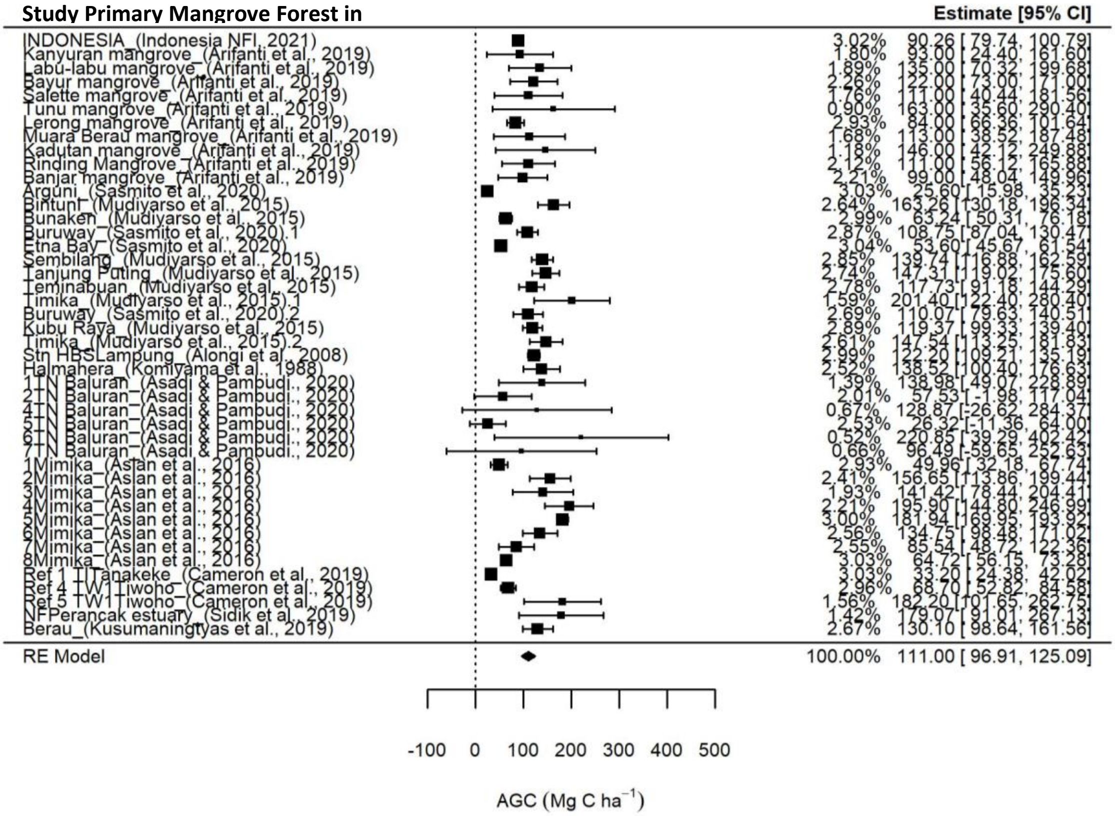
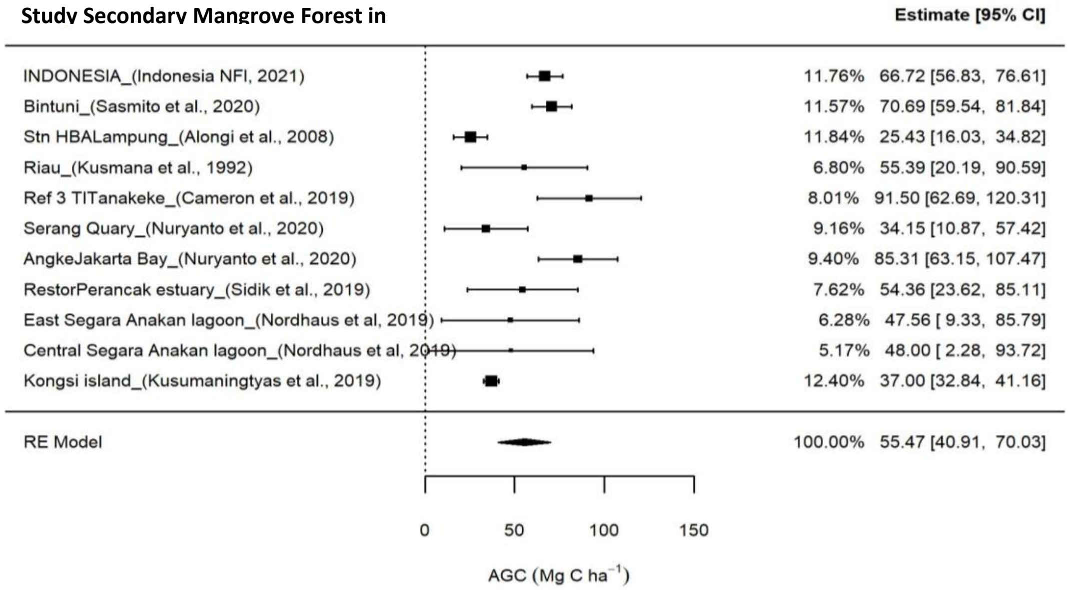
The estimates of AGB stocks and emission factors in each forest type in Indonesia (by main Islands)

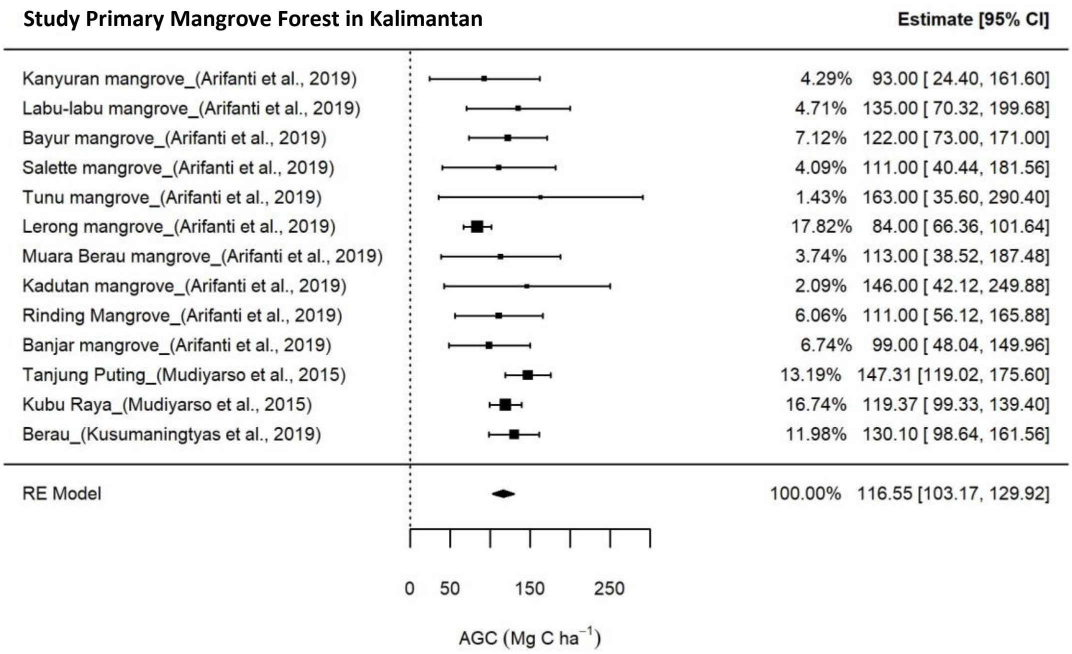
Table Annex 4.1. The Estimates of AGB stocks in Dryland and Swamp Forest in Indonesia (by Main Island)

Main Island	Forest Type	Mean AGB (Mg ha-1)	95% Interval (Mg ha^{-1})	Confidence	N of plot measurements
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				
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

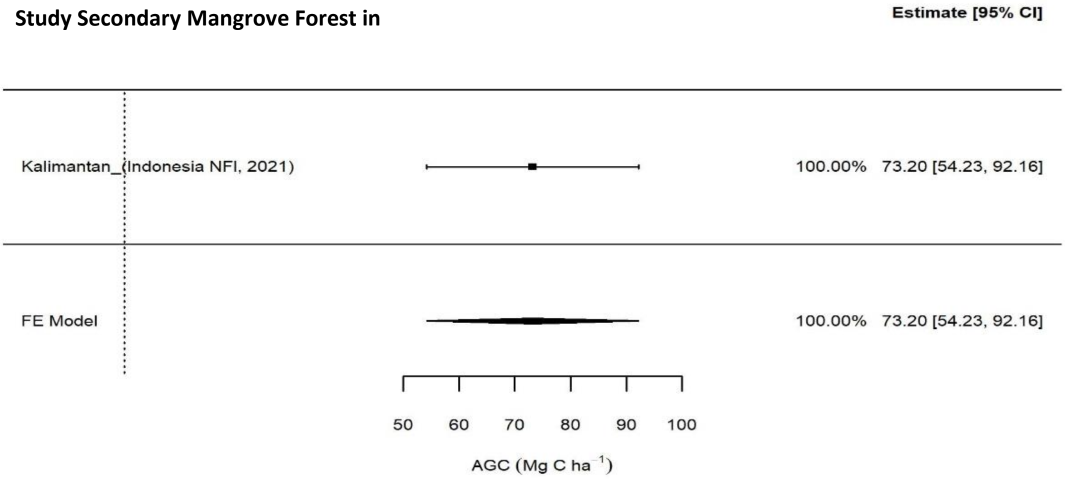
Figure Annex 4.1. Forest plot the estimates of AGB stocks in Mangrove Forest in Indonesia



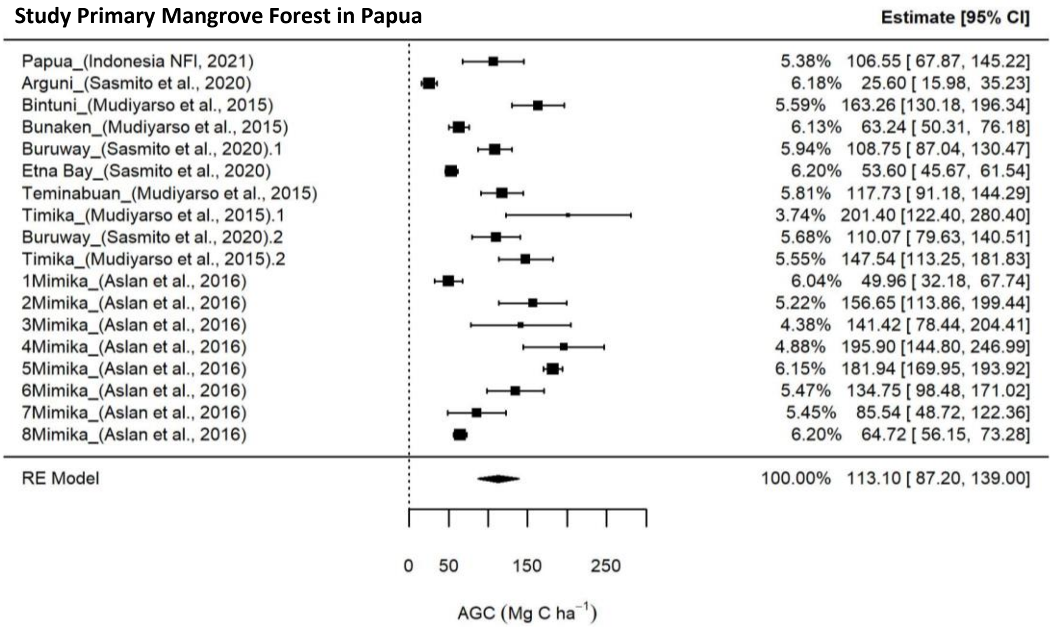




Study Primary Mangrove Forest in Kalimantan
Estimate [95% CI]
Kanyuran mangrove_(Arifanti et al., 2019) 4.29% 93.00 [24.40, 161.60]
Labu-labu mangrove_(Arifanti et al., 2019) 4.71% 135.00 [70.32, 199.68]
Bayur mangrove_(Arifanti et al., 2019) 7.12% 122.00 [73.00, 171.00]
Salette mangrove_(Arifanti et al., 2019) 4.09% 111.00 [40.44, 181.56]
Tunu mangrove_(Arifanti et al., 2019) 1.43% 163.00 [35.60, 290.40]
Lerong mangrove_(Arifanti et al., 2019) 17.82% 84.00 [66.36, 101.64]
Muara Berau mangrove_(Arifanti et al., 2019) 3.74% 113.00 [38.52, 187.48]
Kadutan mangrove_(Arifanti et al., 2019) 2.09% 146.00 [42.12, 249.88]
Rinding Mangrove_(Arifanti et al., 2019) 6.06% 111.00 [56.12, 165.88]
Banjar mangrove_(Arifanti et al., 2019) 6.74% 99.00 [48.04, 149.96]
Tanjung Puting_(Mudiyarso et al., 2015) 13.19% 147.31 [119.02, 175.60]
Kubu Raya_(Mudiyarso et al., 2015) 16.74% 119.37 [99.33, 139.40]
Berau_(Kusumaningtyas et al., 2019) 11.98% 130.10 [98.64, 161.56]
RE Model 100.00% 116.55 [103.17, 129.92]
0 50 150 250
AGC (Mg C ha^{-1})



Study Secondary Mangrove Forest in
Estimate [95% CI]
Kalimantan_(Indonesia NFI, 2021) 100.00% 73.20 [54.23, 92.16]
FE Model 100.00% 73.20 [54.23, 92.16]
50 60 70 80 90 100
AGC (Mg C ha^{-1})



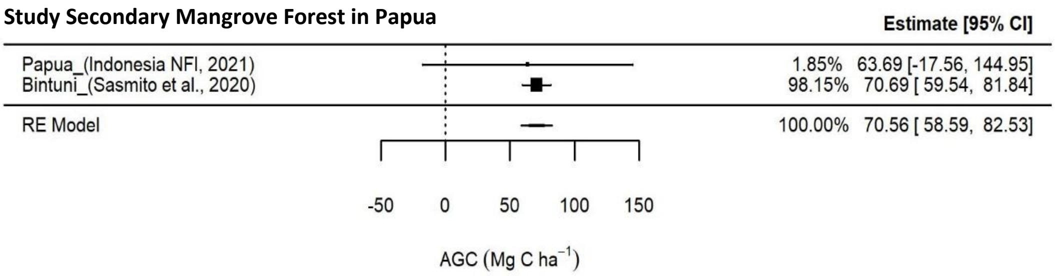


Table Annex 4.2. Summary of the estimates of stocks in Indonesia mangrove forest (by Main Island)

Main Island	Forest Type	Mean AGB (Mg ha-1)	95% Confidence Interval (Mg ha^{-1})		N of plot measurements
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 4.3. The estimates of Carbon stock in each forest type in Indonesia (by Main Island)

Forest Type	Main Island	AGB tree (Mg ha^{-1})		AGB Sapling (Mg ha^{-1})		AGB Understorey (Mg ha^{-1})		Mean BGB (Mg ha^{-1})		Mean Litter (Mg ha^{-1})		Mean Deadwood (Mg 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
	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