Standard Operation Procedures (SOP) for the Lao PDR’s REDD+ MRV: based on the methodologies applied for the 1st FREL/FRL and the 1st National REDD+ Results

October 2020

Contents

1. Introduction

This document provides general guidance linked to calculation spreadsheet to conduct an estimation of the REDD+ results, or often interchangeably referred to as “Measurement, Reporting and Verification: MRV” (for easy read of Lao users, this term will used from hereon), in a consistent manner with the Forest Reference Emission/Forest Reference Level (FREL/FRL) completed in January 2019 and the 1st National REDD+ Results calculation completed in March 2020:

- FREL/FRL can be accessed through https://redd.unfccc.int/submissions.html?country=lao
- 1st National REDD+ REDD+ Results can be accessed through http://dof.maf.gov.la/en/publications/

The document outlines the following processes:

- **Data preparation**; The SOP lists the required data to conduct an estimation of the emissions reduction and removals enhancement. The SOP describes what kind of data estimated based on the Activity Data (AD) and Emission/Removal Factors (E/R F) required including emissions from selective logging.
- **Emissions and Removals calculation**; The SOP describes the steps to calculate emissions and removals for FREL/FRL and MRV including emission from selective logging.
- **Result calculation**; The SOP describes the steps to calculate the emissions reduction and removals enhancement as the result of REDD+ activity from estimated values of FREL/FRL and MRV
- **Uncertainty calculation**; The SOP describes the steps to calculate overall uncertainty of the result based on the uncertainty of FREL/FRL and MRV by using the uncertainty of AD and E/R Factors.

2. Background and Data preparation

2.1. Background of FREL/FRL and MRV

In general, Forest Reference Emission/Forest Reference Level (FREL/FRL) is a benchmark for assessing the performance of implementing REDD+ activities. FREL/FRL is calculated by Activity Data (AD) and Emission/Removal Factors (E/R F) mainly.

The following figures shows the workflow of FREL/FRL development in case of Lao PDR.

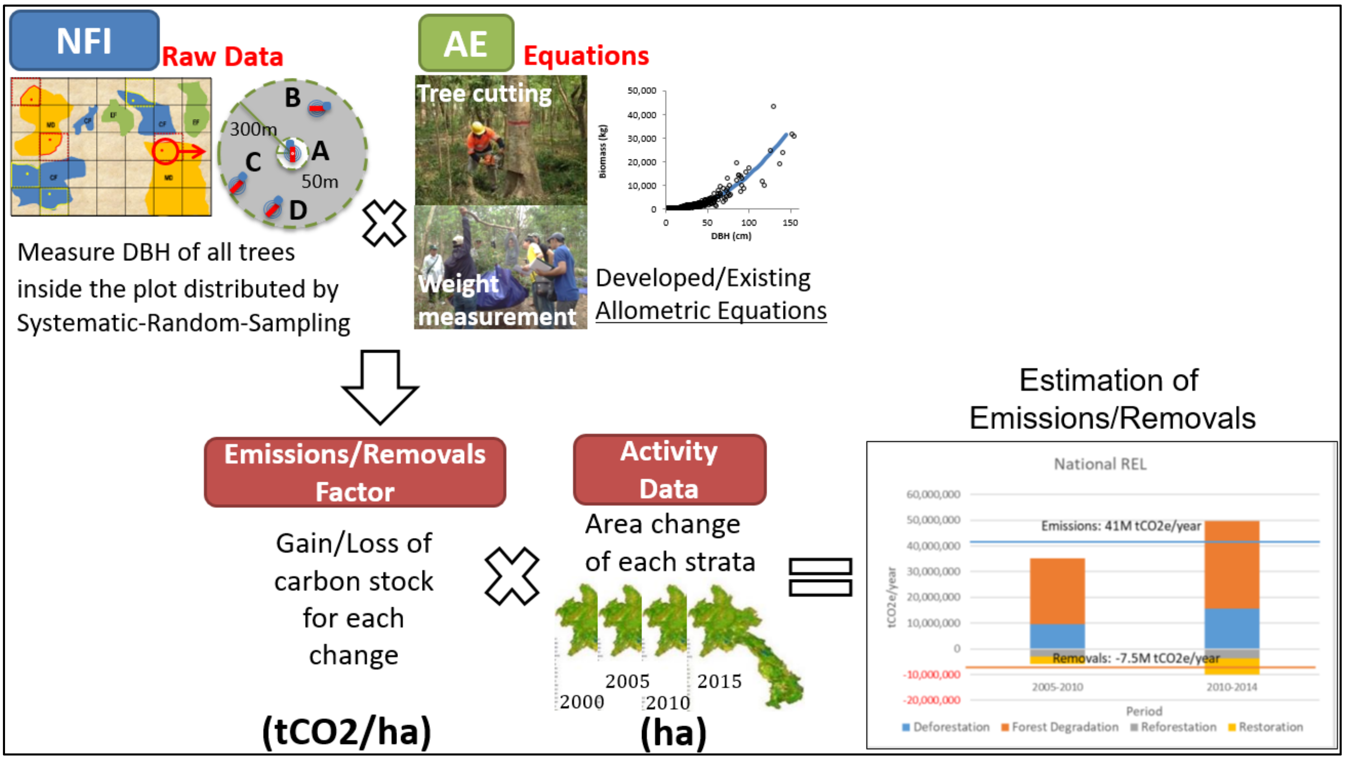

Figure 1: Workflow and required data of National FREL/FRL development in Lao PDR

The Activity Data, expressed in hectares per year, are combined with the Emission/Removal Factors (E/R F) estimated from NFI data and Allometry equations to calculate the national Emissions/Removals during the period.

MRV (Measurement Reporting and Verification) measure the REDD+ performance against the Forest Reference Emissions Level (FREL) as shown in the figure below.

The updated Forest Type Map (FTM) is used in combination with the previous FTM to measure the area of change that are accounted as updated Activity Data. If there is the latest NFI data contribute to updated E/R F estimation. Those updated AD and E/R F are used for estimation of Measurement. The below figure shows the image of FREL and MRV.

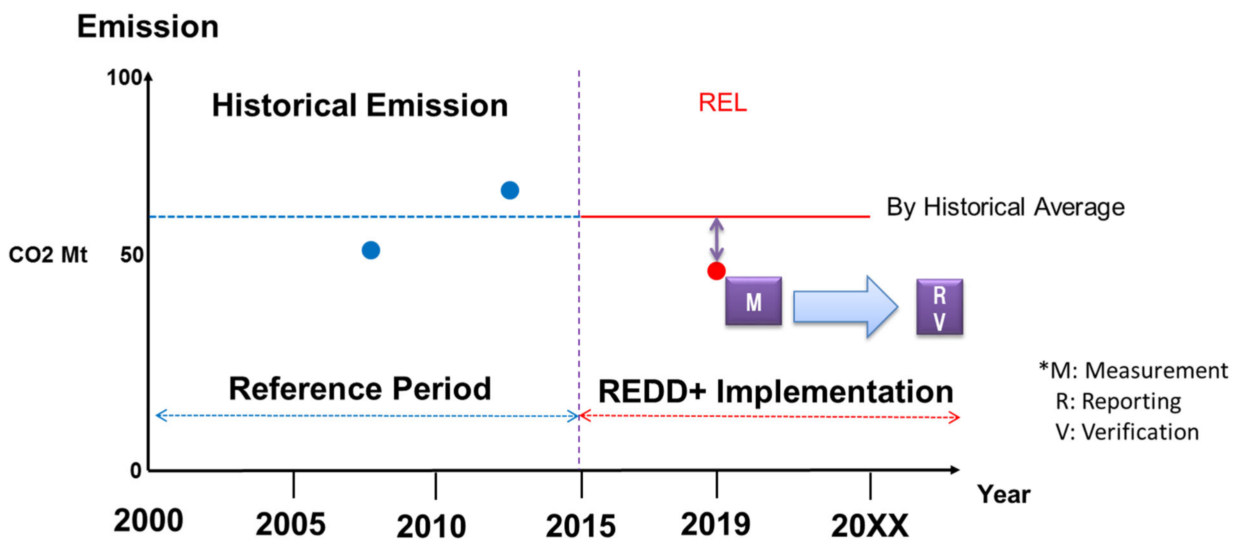

Figure 2. FREL and MRV

In Lao PDR, MRV was implemented in 2019 against for the FREL in the period of 2005-2014

The Forest Type Map (FTM) 2019 is used in combination with the FTM 2015 to measure the area of change that are accounted as updated Activity Data. The 3rd NFI data contribute to updated E/R F estimation. Those updated AD and E/R F are used for estimation of Measurement in the period of 2015 -2018.

For the benefit of the readers, comparison of the scope and methodologies between the FREL/FRL and the REDD+ results are summarized in Table 1 below. Where the methodology used for the estimation of REDD+ results was consistent with that of the FREL/FRL, "Same" is injected to indicate methodological consistency.

Table 1: Comparison of the FREL/FRL and REDD+ results

Scope	FREL/FRL	REDD+ results
Forest definition	"Current Forest" with - Stand DBH: minimum of 10cm - Crown density: minimum of 20% - Minimum area of 0.5ha. and "Potential Forest" defined as lands previously forested, but presently not meeting the definition of "Current Forest" due to various disturbances, and expected to be restored to "Current Forest" status if continuously left undisturbed.	Same.
Land and forest classification system	National land and forest classification system with two levels of classification: - Level 1 consisting of seven classes including "Current Forest" and "Potential Forest"; and - Level 2 which further classifies "Current forest" class under Level 1 into six natural and plantation forest classes.	Same.

Stratification	For the purpose of the REDD+, the national land and forest classification explained above are condensed into five land/forest strata.	Same.
Activities included	· Emission from Deforestation (DF) · Emission from Forest degradation (DG) · Removals from Reforestation (RF) · Removals from Restoration (RS)	Same
Carbon Pools	Included: AGB, BGB Not included: Deadwood, Litter, Soil – lack of data, insignificant	Same.
Gases	Only CO2 included. (Non-CO2 gases from field burning approx. 2.9% of all forest-related CO2).	Same.
Scale	National	Same.
Reference period and proposed validity	2005-2014 (10 years) The validity of FREL/FRL is for the period 2015–2025 (11 years)	The proposed results period is 2015-2018 (4 years) and within the validity period of the FREL/FRL.
Emission Factor	Data source: 2nd NFI; country-specific allometric equation; IPCC default values; data of Vietnam. Then, stratified into five strata. Calculation: Amount of changes in carbon stock of among the five strata.	Data source: 3rd NFI; Otherwise same.
Activity Data	Data source: National-scale forest type maps for year 2005, 2010 and 2015. Then, stratified in to five strata. Calculation: Amount of changes in areas among the five strata. Estimated through reference sampling ('Design-Based Area Estimation')	Data source: National-scale forest type maps for year 2019. Otherwise same.
Model applied	Historical average	Same.
Adjustment	No.	Same.

2.2. Data preparation

To conduct the estimation of the REDD+ result through the calculation of the FREL/FRL and MRV, several datasets described in this section are required.

Activity Data

The Activity Data (AD) are developed through two-folded process, namely:

1) Development of Forest Type Maps of Lao PDR for years 2005, 2010, 2015,2019; and

2) Application of the forest type stratification (i.e. into five strata) to the Forest Type Maps and initial analysis of forest cover change which are used to conduct design-based area estimation of the changes in forest areas (Activity Data) which relate to any of the four (4) sources and sinks.

It should be note that the methods explained in this section only discuss the emissions and removals estimated by the use of spatially explicit AD, as the amount of changes in areas which relate to any of the four sources and sinks: Emissions from Deforestation and Degradation, Removals from Restoration and Reforestation.

The AD for FREL/FRL is estimated by using the FTM 2005, 2010 and 2015.

The AD (called updated AD) for MRV is estimated by using the FTM 2015 and 2019.

The detail process and result is shown in the AD report[1][2]

Emission/Removal Factors

The Emission and Removal factors (E/R factors) are developed for each type of land/forest cover change, stratified into five land/forest strata, and by taking the difference in carbon stock of each land/forest strata.

The sources of E/R factors consists of a combination of national dataset, and other data from Vietnam and IPCC defaults which are regarded as the best available options.

As the emissions and removals are calculated based on the changes among the five land/forest strata, the average carbon stock for the strata was calculated by using weighted values as follows:

$$Cstrata\ (tC/ha) = (C1*A1 + C2*A2 + \ldots + Cn*An)/(A1 + A2 + \ldots + An)$$

Where:

Cstrata = average carbon stock (tC/ha) of strata calculated from carbon stock and area of land/forest class;

Ci = carbon stock of land/forest class (tC/ha);

Ai = area (ha) of land/forest class in 2015/2019.

The E/R Factors for FREL/FRL is estimated by using the 2nd National Forest Inventory, 1st Regenerating Vegetation survey data, developed allometry equations and data and equations from IPCC Guidelines.

The E/R Factors (called updated E/R Factors) for MRV is estimated by using the 3rd National Forest Inventory, 2nd Regenerating Vegetation survey data, developed allometry equations and data and equations from IPCC Guidelines.

The detail process and result is shown in the E/R Factors report[3][4]

Logging data for emission from forest degradation

[1] Lao People's Democratic Republic Forest Reference Emission Level and Forest Reference Level for REDD+ Results Payment under the UNFCCC, Annex 1 Activity Data Report

[2] Lao People's Democratic Republic 1st National REDD+ Results Report for REDD+ Results Payment under the UNFCCC, Annex 1 Activity Data Report

[3] Lao People's Democratic Republic Forest Reference Emission Level and Forest Reference Level for REDD+ Results Payment under the UNFCCC, Annex 2 Emission/Removal Factors Report

[4] Lao People's Democratic Republic 1st National REDD+ Results Report for REDD+ Results Payment under the UNFCCC, Annex 2 Emission/Removal Factors Report

The 2nd and 3rd NFI recorded the diameter and height of tree stumps observed in the measurement plots. By using this data the FREL/FRL and MRV estimate the historical emissions caused by selective logging.

From the NFI's records, the following five parameters are required for the estimation of emissions

1. Height (H) - below 1.3m
2. Smallest Diameter (D_1) – the smallest diameter across the top of the stump
3. D_2 – the diameter at a 90^o angle to D_1.
4. Locational information (Latitude / Longitude)
5. Instrument used for tree felling (e.g. machine, saw axe)

3. Workflow

Estimation of the Emissions and Removals

The estimation of the Emissions and removals follows several steps shown in Figure 3 and further described in the following sections.

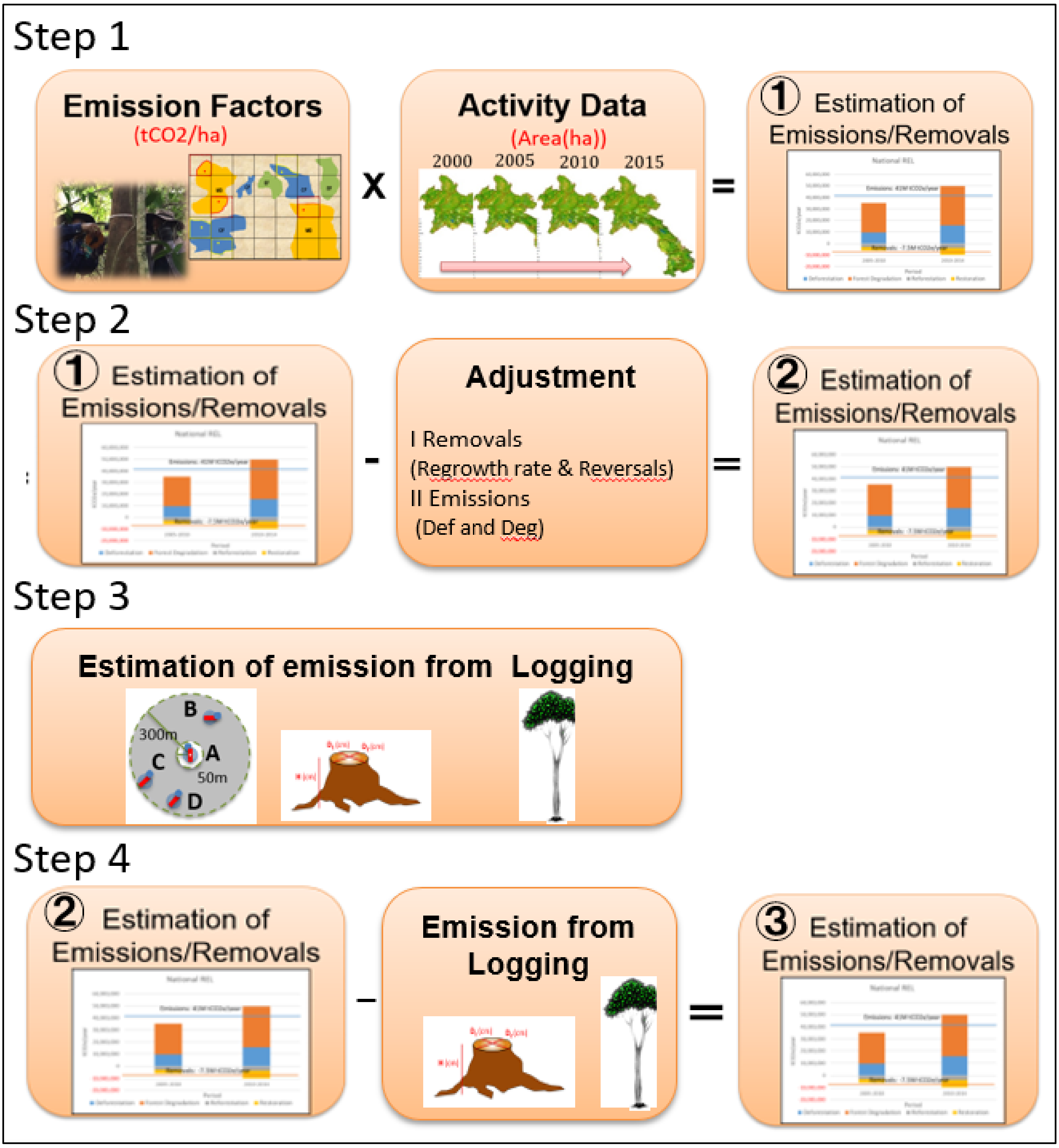

Figure 3. Workflow of estimation of emissions and removals

【Step 1】

The first step is the estimation of average annual historical emissions and removals based on the changes among land/forest strata over the reference period of 2005-2014/2015-2018.

【Step 2】

As step 2, subtract the value calculated by the above adjustment from average annual historical emissions and removals estimated by step 1.

Two adjustments were made with an aim to make the estimation as accurate as possible as step 2:

i) Adjustment of removals (regrowth rate and reversals)

   a. By considering the types of changes and rate of tree growth. This recognizes that in forest ecosystems, forest biomass increase slowly over time to reach their full biomass (IPCC 2006)[5].
   b. Reversals during the reference period (2005-2014) were identified through time-series analysis of polygons, in order to avoid double-counting. This is because due to the estimation method of generating AD for two independent periods (i.e. 2005-2010 and 2010-2014), there is a chance that the emissions from reversal events which have occurred during the reference period are unreported (in other words, removals are over-estimated). This is done by tracking all the change patterns which are regarded as reversals (e.g. strata 4 in 2005, changed to stratum 2 in 2010 and reverted back to stratum 4 in 2014). The results were deducted as over-estimated removals.

ii) Adjustment of emissions from deforestation and degradation

The resulting estimation (based on above) presents the risk of overestimation of emissions from deforestation and degradation. This is because, the E/R factors are strata-specific and do not reflect the actual accumulated biomass which may be lower. For example, a MD forest which is in its early regrowth stage (e.g. 10th year) should have lower biomass than the average biomass of entire MD class including all its age ranges. If for example a land parcel shifted from strata 4, strata 3, and back to strata 4, the indication would be that the strata 3 forests before the disturbance event would have reached at maximum, only about 10-11 years. Such change patterns are tracked through the time-series-analysis of forest maps. The resulting over-estimation of emissions from deforestation and forest degradation are estimated and deducted, respectively.

【Step 3】

Historical emission from logging caused by selective logging is included as emission from forest degradation in Lao PDR. Detail methodology to estimate the emission will be shown in the Section 4.3.

【Step 4】

As final step, emission from forest degradation estimated by AD and E/R factors are deducted to avoid double counting of emission from selective logging.

The biomass of the felled trees were estimated from the measured size of each tree stump, aggregated for each of the five forest class (i.e. EG, MD, DD, CF, CF) in order to estimate the average loss of carbon stock, and converted to tCO2e. Then, the results were multiplied with the area of each forest class calculated from the Forest Type Map 2015/2019, to estimate the assumed emissions from such logging events

[5] IPCC (2006, Volume 4, Chapter 4.3: Land Converted to Forest Land) suggests default period of 20 year time interval for forest ecosystems to be established.

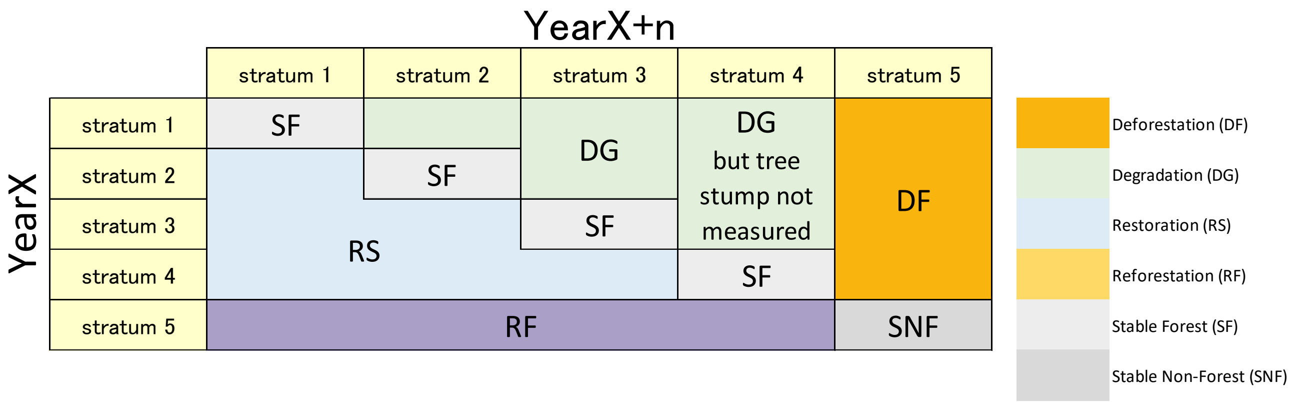

Figure 4: Annotated change matrix among land/forest strata for addressing double-counting in degradation

As in Figure 4, emissions from forest degradation estimated through the stratified Forest Type Maps are represented in DG1, DG2 and DG3 (note that tree stumps were not measured in Stratum 4).

In Strata 1, 2 and 3 (therefore, DG1, DG2, DG3, and SF1, SF2, SF3), tree stumps were measured during the NFI. Using these measurements, emissions from selective logging were estimated.

As a result, in DG1, DG2 and DG3, emissions from the Forest Cover Change Matrix and from selective logging are both represented, and parts of such emissions are assumed to be overlapping (i.e. double-counted). To avoid such double counting, either one of the forest degradation sources should be deducted from the estimation.

<u>Estimation of the Result (Emissions Reductions and Removals Enhancement)</u>

The REDD+ result is estimated to compare annual average emissions and removals of FREL/FRL (2005-2014) and MRV (2015-2018). The emissions reduction is calculated by deducting annual average emissions of FREL/FRL by the annual average emission of MRV. If the emission is decreased in the period of MRV, the result is shown as positive. The removals enhancement is calculated by deducting annual average removals of MRV by the annual average removals of FREL/FRL. If the removals is increased, the result becomes positive.

<u>Uncertainty assessment</u>

Uncertainty associated with AD and E/R factors is quantified by providing accuracy, confidence interval, distribution error and propagation of error following the 2006 IPCC Guidelines for National GHG Inventory (Chapter 3). The quantification method applied is simple error propagation equations, since errors in data and methods are not considered large as defined in the IPCC Guideline.

Apart from the above, the uncertainty associated with selective logging is assessed.

4. SOP Estimation of the Emissions and Removals

4.1. General Methodology

Related spread sheet in this section.

- Annex1 Sheet ①～⑤
- Annex2 Sheet ①～⑤

In Lao PDR, the period of FREL/FRL is defined as 2005-2014. The period of MRV is 2015-2018. The methodology of emissions and removals estimation are the same for both FREL/FRL and MRV generally. The following description explain the methodology for both FREL/FRL and MRV.

Reflecting the dynamic nature of land-use change in the country, and also to adequately monitor the future impacts of REDD+ implementation, Lao PDR considers it more appropriate to present historical emissions and removals separately per each source and sink activity. Accordingly, the four sources and sinks (i.e., emissions from deforestation and degradation, and removals from restoration and reforestation) are estimated by calculating the changes in biomass caused by the shift from one REDD+ strata to another.

Generally, methodologies for calculating emissions and removals follow the guidelines of Intergovernmental Panel on Climate Change (IPCC) 2006 mainly.

Considering the available nationally derived data, Lao PDR applies an approach principally following the gain-loss method in calculating the average annual historical emissions and removals over the reference period, using Activity Data (AD) and Emission/Removal Factors (E/R factors). However, both emissions and removals occurring in forests remaining in the same category are not accounted, except in the case of emissions from selective logging estimated through measurement of tree stumps as a proxy data. For land converted to other land-use, the equation below is used.

EQUATION 2.15

ANNUAL CHANGE IN BIOMASS CARBON STOCKS ON LAND CONVERTED TO OTHER LAND-USE CATEGORY (TIER 2)

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

(Source: 2006 IPCC GL, Volume 4, Chapter 2)

Where:

ΔC_B = *annual change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr-1*

ΔC_G = *annual increase in carbon stocks in biomass due to growth on land converted to another land-use category, in tonnes C yr-1*

$\Delta C_{CONVERSION}$ = *initial change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr-1*

ΔC_L = *annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr-1*

However, it is noted that due to lack of datasets, Lao PDR is currently not able to separately account carbon gains (ΔC_G) and carbon losses (ΔC_L) due to land-use change, instead, they are combined into a single emission estimate as represented in the equation below.

EQUATION 2.16
INITIAL CHANGE IN BIOMASS CARBON STOCKS ON LAND CONVERTED TO ANOTHER LAND CATEGORY

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \bullet \Delta A_{TO\_OTHERS_i}\} \bullet CF$$

(Source: 2006 IPCC GL, Volume 4, Chapter 2)

Where:

$\Delta C_{CONVERSION}$	= *initial change in biomass carbon stocks on land converted to another land category, tonnes C*
B_{AFTERi}	= *biomass stocks on land type i after the conversion, tonnes d.m. ha-1*
$B_{BEFOREi}$	= *biomass stocks on land type i before the conversion, tonnes d.m. ha-1*
$\Delta A_{TO\_OTHERSi}$	= *area of land use i converted to another land-use category, ha*
CF	= *carbon fraction of dry matter, tonnes C (tonnes d.m.)-1*
i	= *type of land use converted to another land-use category*

Regarding the AD and E/R factors:

- The AD is generated spatially using satellite-based analysis of land/forest cover for the two periods: 2005-2010 and 2010-2014 as for FREL/FRL and 2015-2018 for MRV. National-scale Forest Type Maps are used as the basis for estimating the AD. Changed areas are detected by change detection method, and then applied design-based area estimation with respect to generating statistically reliable estimates.
- E/R factors are basically generated using national-scale biomass data from the 2nd and 3rd National Forest Inventory combined with country-specific allometric equations, and an independent biomass measurement data for RV class[6]. IPCC default and data from neighboring Vietnam are used for some land/forest classes where no country-specific data are available.

Apart from the above, Lao PDR estimates emissions from forest degradation by selective logging through proxy approach (see Section 4.3). The approach uses the tree stump records measured through the 2nd and 3rd NFI to complement the impact of selective logging which was considered as under-represented. The approach also complements quantifying forest degradation in stable forest classes where forest biomass data is limited.

The following figures shows the example of average annual historical emissions and removals calculation over the reference period, using Activity Data (AD) and Emission/Removal Factors (E/R factors).

[6] The reason for not using the 1st NFI data is explained in the Annex 10: Emission and Removal Factors Report.

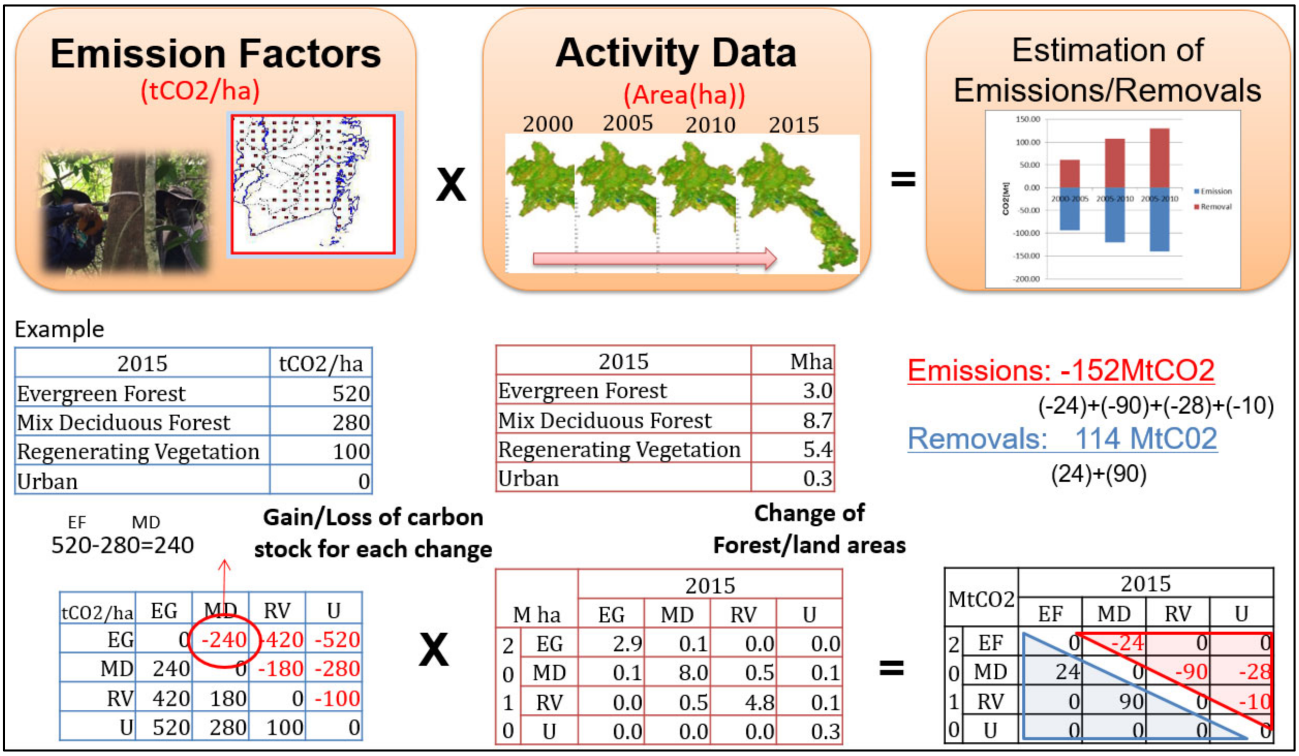

Figure 5: Examples of Emissions and Removals calculation

4.2. Adjustment of Emissions and Removals

Related spread sheet in this section.

- Annex1 Sheet ⑤, ⑩, ⑪
- Annex2 Sheet ⑤, ⑩, ⑪

Based on the calculation method explained in Section 4.1, average annual historical emissions and removals based on the changes among land/forest strata over the reference period of 2005-2014 and 2015-2018 are calculated.

Further, two adjustments were made with an aim to make the estimation as accurate as possible:

i) Adjustment of removals (regrowth rate and reversals)

For land cover changes which result in emissions (i.e. ‘Deforestation’ and ‘Forest Degradation’), the entire expected emission is assumed to occur (i.e. evenly distributed) over the time period in question. Meanwhile, for land/forest cover changes which result in removals (i.e. ‘Restoration’ and ‘Reforestation’) adjustments were applied as follows;

a. Adjustments were made based on the typology summarized below, by considering the types of changes and rate of tree growth. This recognizes that in forest ecosystems, forest biomass increase slowly over time to reach their full biomass (IPCC 2006)[7].

Table 2: Typologies of change for removals

[7] IPCC (2006, Volume 4, Chapter 4.3: Land Converted to Forest Land) suggests default period of 20 year time interval for forest ecosystems to be established.

Sinks	From	To	Adjustment of removals
Restoration	Stratum 4 (RV)	Stratum 1, 2 and 3	In principle, 40-years[8] is assumed as the transition period from non-forest to Current Forest (i.e. Stratum 1, 2 and 3). From there, deduct 5 years as period for RV to reach its average biomass stock (See RV Survey Report), to arrive at 35 years for the transition period for biomass of Stratum 4 to reach Stratum 1, 2 and 3.
	Stratum 2 (MD, CF and MCB) Stratum 3 (DD)	Stratum with higher biomass	In principle, 20 years[9] is assumed as the transition period for forest with lower biomass to reach forest with higher biomass.
Reforestation	Stratum 5 (non-forest)	Stratum 4 (predominantly, RV)	In principle, the full removal factor is applied at the time change is observed, as RV reaches its average biomass stock after 5 years (See RV Survey Report)[10]. Adjustment based on 40-years default applied to the years following.
	Stratum 5 (non-forest)	Stratum 1, 2 or 3	No such change observed.

b. Reversals during the reference period (2005-2014) and MRV period (2015-2018) were identified through time-series analysis of polygons, in order to avoid double-counting. This is because due to the estimation method of generating AD for two independent periods (i.e. 2005-2010 and 2010-2015) for FREL/FRL and three independent periods(i.e. 2005-2010, 2010-2014 and 2015-2018) for MRV, there is a chance that the emissions from reversal events which have occurred during the FREL/FRL period and MRV period are unreported (in other words, removals are over-estimated). This was done by tracking all the change patterns which are regarded as reversals (e.g. strata 4 in 2005, changed to stratum 2 in 2010 and reverted back to stratum 4 in 2015 for the FREL/FRL period as shown in Table 3; and MRV as shown in Table 4 below). The respective estimated areas were multiplied with the accumulated biomass of the respective stratum calculated based on typologies in Table 2 above, and the results were deducted as over-estimated removals. The resulting over-estimation from such removals, which was 212,539 tCO_2e, were deducted from "Restoration" of 2010-2014 period and 602,179 tCO_2e, were deducted from "Restoration" of 2015-2018 period.

Table 3: Over-estimated removals tracked for FREL/FRL period

[8] The assumption is based on references in the FCPF Carbon Fund Emissions Reduction Program Document of neighboring Vietnam, which assumes 40 years for a non-forest to reach "Evergreen broadleaf forest – Medium". The Lao experts agreed on this assumption, as rather conservative. The actual mapping cycle of 6 years and 4 years are also reflected in the actual calculation (See footnote 11 in Section 4.2.1).

[9] Again, following the case of Vietnam where 20 years is assumed as a period for forest with lower biomass shift to forest with higher biomass. However, such changes are actually rare: 71 ha for 2005-2010 and nil for 2010-2015. The actual mapping cycle of 6 years and 4 years are also reflected in the actual calculation.

[10] The actual mapping cycle of 6 years and 4 years are also reflected in the actual calculation.

	Stratum in 2005	Stratum in 2010	Stratum in 2015	Estimated area (ha)*	Emissions to be deducted from Reversals (tCO2e)
Change patterns from time series	**4**	**2**	**3**	**2**	**73**
	4	**2**	**4**	**3,616**	**106,256**
	4	**2**	**5**	**3,546**	**104,200**
	4	**3**	**4**	**4**	**44**
	4	**3**	**5**	**1**	**11**
	4	**1**	**5**	**1**	**113**
	2	**1**	**4**	**5**	**411**
	2	**1**	**5**	**17**	**1,430**
Total					**212,539**

*The estimated area was calculated by adjusting the area from the time-series-data with the ratio of sources and sinks derived from the design-based area estimation for 2005-2010 period. The actual mapping cycle of 6 years and 4 years are also reflected in the calculation.

Table 4: Over-estimated removals tracked for MRV period

	Stratum in 2005	Stratum in 2010	Stratum in 2015	Stratum in 2019	Estimated area (ha)	Emissions to be deducted from Reversals (tCO_2e)
Change patterns from time series	**4**	**2**	**3**	**any stratum**	**2**	**79**
	4	**2**	**4**	**any stratum**	**3,615**	**115,542**
	4	**2**	**5**	**any stratum**	**3,547**	**113,364**
	4	**3**	**5**	**any stratum**	**5**	**86**
	4	**1**	**5**	**any stratum**	**1**	**121**
	2	**1**	**4**	**any stratum**	**5**	**434**
	2	**1**	**5**	**any stratum**	**17**	**1,508**
	any stratum	**4**	**2**	**5**	**2,668**	**85,263**
	any stratum	**4**	**2**	**4**	**2,719**	**86,901**
	any stratum	**4**	**3**	**5**	**4**	**61**
	any stratum	**5**	**4**	**5**	**18,798**	**94,037**
	4	**2**	**2**	**4**	**1,558**	**49,784**
	4	**2**	**2**	**5**	**1,697**	**54,240**
	4	**3**	**3**	**4**	**19**	**321**
	4	**3**	**3**	**5**	**26**	**434**
	Total					**602,179**

ii) Adjustment of emissions from deforestation and degradation

The resulting estimation (based on above) presents the risk of overestimation of emissions from deforestation and degradation. This is because, the E/R factors are strata-specific and do not reflect the actual accumulated biomass which may be lower. For example, a MD forest which is in its early regrowth stage (e.g. 10th year) should have lower biomass than the average biomass of entire MD class including all its age ranges. If for example a land parcel shifted from strata 4, strata 3, and back to strata 4, the indication would be that the strata 3 forests before the disturbance event would have reached at maximum, only about 10-11 years. Such change patterns were tracked through the time-series-analysis of forest maps as shown in

Table 5 and below. The respective estimated areas were multiplied with the accumulated biomass of each land calculated based on typologies in Table 2 above. The resulting over-estimation of emissions from deforestation, which was 788,306 tCO_2e, and over-estimation of emissions from forest degradation, which was 502,065 tCO_2e, were estimated and deducted from emission of FREL/FRL, respectively. Also, the resulting over-estimation of emissions from deforestation, which was 1,304,610 tCO_2e, and over-estimation of emissions from forest degradation, which was 943,945 tCO_2e, were estimated and deducted from emission of MRV, respectively

Table 5: Tracked over-estimation of emissions for FREL/FRL period

	Stratum in 2005	Stratum in 2010	Stratum in 2015	Estimated area (ha)	Overestimation of emissions to be deducted (tCO_2e)
Change patterns from time series	**4**	**1**	**5**	**1**	**765**
	4	**2**	**3**	**2**	**220**
	4	**2**	**4**	**2,348**	**500,117**
	4	**2**	**5**	**3,087**	**779,843**
	4	**3**	**4**	**3**	**208**
	4	**3**	**5**	**1**	**104**
	2	**1**	**4**	**3**	**1,520**
	2	**1**	**5**	**15**	**7,595**
Total					**1,290,372 (Def.: 788,306) (Deg.: 502,065)**

*The estimated area was calculated by adjusting the area from the time-series-data with the ratio of sources and sinks derived from the design-based area estimation for 2010-2015 period. The actual mapping cycle of 6 years and 4 years are also reflected in the calculation (See footnote 13 in Section 4.2.1)

Table 6: Tracked over-estimation of emissions for MRV period

	Stratum in 2010	Stratum in 2015	Stratum in 2019	Estimated area (ha)	Overestimation of emissions to be deducted (tCO_2e)
Change patterns from time series	**5**	**4**	**5**	**9,472**	**189,529**
	4	**2**	**4**	**3,811**	**943,906**
	4	**2**	**5**	**4,129**	**1,114,261**
	4	**3**	**5**	**5**	**820**
Total					**2,248,555 (Def.: 1,304,610) (Deg.: 943,945)**

4.3. Emissions from logging

Related spread sheet in this section.

- Annex3 sheet "work"
- Annex4 sheet "work"

3rd NFI recorded the diameter and height of tree stumps observed in the measurement plots. By using this data, historical emission from logging caused by selective logging is estimated through the following steps:

In the 2nd and 3rd NFI, tree stumps are measured in all plots when observed.

For stumps, five parameters were measured:

1. Height (H) - below 1.3m
2. Smallest Diameter (D_1) – the smallest diameter across the top of the stump
3. D_2 – the diameter at a 90° angle to D_1.
4. Locational information (Latitude / Longitude)
5. Instrument used for tree felling (e.g. machine, saw axe)

Procedure for biomass loss estimation:

1. Calculate average diameter D from D 1 and D 2 for each stump
2. Exclude stumps that were not felled by "machine" or "saw axe" (to exclude incidents of natural disturbances)
3. Estimate the DBH from the diameter at the base and height by using the following equation developed in Cambodia[11] :

   DBH=D – (-C1 ln (H+1.0)-C1 ln (2.3))

   Where:
   D=Average Diameter of stump, H=Height of stump,
   Ln (|C1|)=d0+d1*D+d2*H+d3*D*H
   d0=1.68, d1=0.0146, d2=-0.82, d3=0.0068

5. Estimate the AGB by using the allometric equation used in the 2nd NFI
6. Convert the AGB loss by using an area ratio (t/ha)
7. Sum up the AGB loss by sub-plot (one survey plot consists of four sub-plots)
8. Estimate plot average AGB loss (t/ha) by dividing the sum of AGB loss above by four (including non-stump plot)
9. Estimate average AGB loss(t/ha) for each forest class by dividing the total number of plot of each forest class
10. Estimate BGB loss by using default conversion factor found in the IPCC 2006 Guideline
11. Convert biomass to CO2 with the same conversion factor for estimating the carbon stock
12. Estimate total loss tCO2e by multiplying above value by the area of Forest Type Map 2015 for each forest class.

[11] Ito et al., 2010. Estimate Diameter at Breast Height from Measurements of Illegally Logged Stumps in Cambodian Lowland Dry Evergreen Forest. JARQ 44(4),440

The above method allows an estimation of the biomass loss (and thereby, the emissions) from selective logging. However, it does not give information on when the trees were actually felled, which is essential for accounting the results in the FREL/FRL and MRV.

An equation which allows the estimation of years required for wood materials to decompose from the experimental study in Pasoh in the Malaysian Peninsula[12] was referenced. Figure 6 below shows the change of relative value of material weight under different temperatures (Table 7) and climate conditions (e.g. precipitation) which is considered to be reasonably similar to that of Lao PDR.

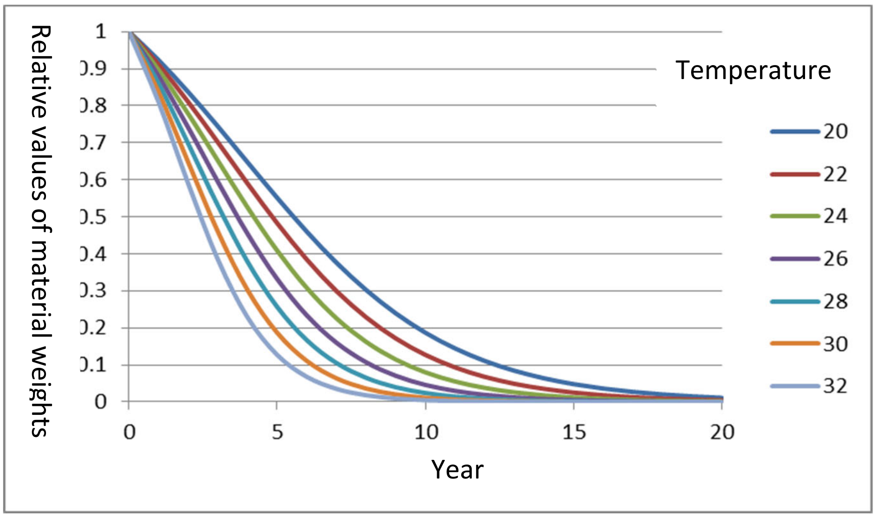

Figure 6: Relative values of material weights over years

Table 7: Loss of material weights over years based on temperature

Temperature (°C)	20	22	**24**	**26**	28	30	32
50% loss(year)	5.6	4.6	4.0	3.5	3.1	2.7	2.3
95% loss(year)	14.6	12.7	11.1	9.6	8.4	7.3	6.3

As in the following Table 8, the average temperature of Lao PDR is 26.9 °C. Assuming a cooler temperature of 24-26 °C in the forest, 3.7-4.2 years are required for 50% loss (decomposition) of a stump and 9.8 -11.3 years for 95% loss. Accordingly, it is considered reasonable to assume that the stumps observed and recorded in the 2nd NFI were felled within 12 years before its field survey (implemented in dry season of 2015-2016 and 2016-2017). 3rd NFI was implemented in dry season of 2019. Thus, emission from selective logging for the result is adequate to use only for two years (2017 and 2018).

Table 8: Temperature and precipitation in Lao PDR (2014) [13] and Pasoh (study site)

	Temperature	Precipitation
	°C	mm/Y
Luang Prabang	26.6	1469

[12] Yoneda et al., 2016. Inter-annual variations of net ecosystem productivity of a primeval tropical forest basing on a biometric method with a long-term data in Pasoh, Peninsular Malaysia. TROPICS Vol. 25 (1) 1-12

[13] Lao Statistics Bureau (http://www.lsb.gov.la/en/Meteorology14.php)

Vientiane capital	27.0	1349
Savannakhet	26.5	1461
Champasack	27.3	2416
Average	***26.9***	*1674*
Pasoh*	25.5	1724.4

*Recorded in the forest

As explained in above, the 2nd and 3rd NFI recorded the tree stumps of the trees felled by human activities. The biomass of the felled trees were estimated from the measured size of each tree stump, aggregated for each of the five forest class (i.e. EG, MD, DD, CF, CF) in order to estimate the average loss of carbon stock, and converted to tCO2e. Then, the results were multiplied with the area of each forest class calculated from the Forest Type Map 2015 and 2019, to estimate the assumed emissions from such logging events as shown in Table 9 below.

Table 9: Estimated total emissions from selective logging for FREL/FRL period

	Average loss (tCO2e/ha)	StD	Area from Forest Type Map 2015 (ha)	tCO2e/12 year
EG: Evergreen Forest	17.8	39.3	2,605,557	46,353,989
MD: Mixed Deciduous Forest	4.8	11.3	9,205,036	44,531,308
DD: Dry Dipterocarp	14.3	18.3	1,188,198	16,995,658
CF: Conifer Forest	2.7	9.7	124,772	336,245
MCB: Mixed Conifer and Broadleaved forest	18.8	37.7	107,880	2,024,360
Total				**110,241,559**
Annual average (tCO2e) (Total divided by 12 years)*				**9,186,797**

Table 10: Estimated total emissions from selective logging for MRV period

	Average loss (tCO2e/ha)	Area from Forest Type Map 2019 (ha)	tCO2e/12 year[14]
EG: Evergreen Forest	11.4	2,594,961	29,646,105
MD: Mixed Deciduous Forest	5.8	9,036,767	51,974,068
DD: Dry Dipterocarp	11.6	1,171,873	13,541,141
CF: Conifer Forest	13.1	124,009	1,626,038
MCB: Mixed Conifer and Broadleaved forest	9.0	106,848	965,339
Total			**97,752,691**
Annual average (tCO2e) (Total divided by 12 years)[15]			**8,146,058**

[14] It is considered reasonable to assume that the stumps observed and recorded were felled within 12 years before its field survey. The details are presented in Section 4.2.3 of the FREL/FRL Report.
[15] As the 2nd NFI in fact includes tree stumps of 2015 and 2016, this data represents only the tree stumps of 2017 and 2018.

4.4. Adjustment for avoiding double counting on emission from forest degradation

Related spread sheet in this section.

- Annex1 Sheet ⑥
- Annex2 Sheet ⑥

The historical emissions and removals calculated based on land/forest strata as explained in Section 4.2, and the emissions from selective logging as explained in Section 4.3.

However, if the latter is simply added to the former, the problem of double-counting of emissions occurs.

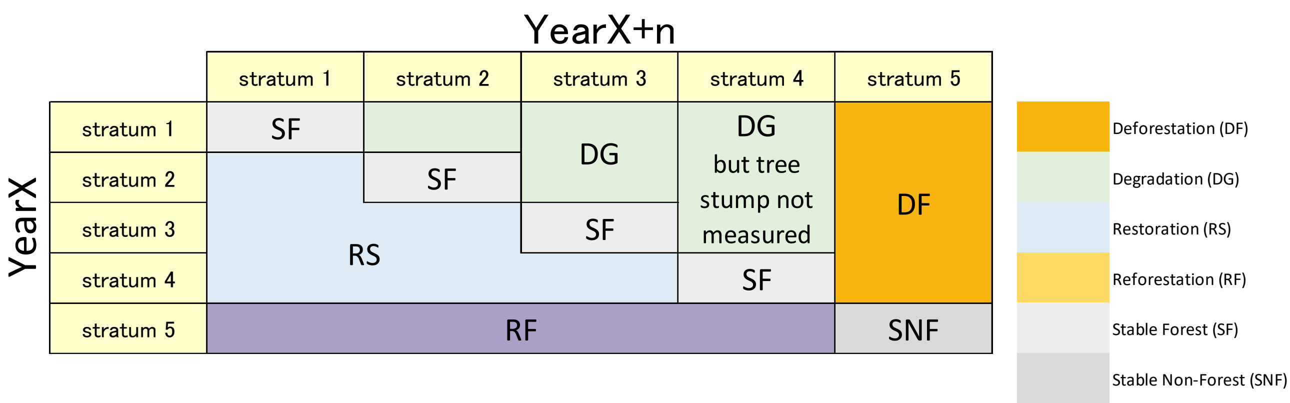

Figure 7: Annotated change matrix among land/forest strata for addressing double-counting in degradation

As in Figure 7, emissions from forest degradation estimated through the stratified Forest Type Maps are represented in DG1, DG2 and DG3 (note that tree stumps were not measured in Stratum 4). Forest degradation occurring within a single forest strata, are represented in SF1, SF2, SF3 (and SF4); these are not accounted for in the FREL/FRL (c.f. Section 3.1).

In Strata 1, 2 and 3 (therefore, DG1, DG2, DG3, and SF1, SF2, SF3), tree stumps were measured during the NFI. Using these measurements, emissions from selective logging were estimated.

As a result, in DG1, DG2 and DG3, emissions from the Forest Cover Change Matrix and from selective logging are both represented, and parts of such emissions are assumed to be overlapping (i.e. double-counted). To avoid such double counting, either one of the forest degradation sources should be deducted from the estimation. Considering that the emissions from selective logging cannot be accurately associated with the Forest Cover Change Matrix[16], the option to deduct the emissions from the Forest Cover Change Matrix in DG1, DG2, and DG3, is selected. The following steps of estimations are applied (noting that figures have been rounded to the nearest whole number):

a. The emissions from forest degradation based on changes among land/forest strata (i.e. DG1 + DG2 + DG3 + DG) = 19,983,348 tCO2e/year.
b. The emissions from forest degradation based on changes among land/forest strata within the stratum (i.e. DG1 + DG2 + DG3) = 153,667 tCO2e/year.

[16] The timing of the felling of the tree stump cannot be accurately determined, making the association with the Forest Cover Change Matrix a challenge.

c. The emissions from selective logging (included in SF1, SF2, SF3, DG1, DG2, DG3) = 9,186,797 tCO2e/year.

   The total emissions from forest degradation is therefore 29,016,478 tCO2e/year
   (19,983,348 (a) – 153,667 (b)) + 9,186,797 (c) = 29,016,478 tCO2e/year

Same with the FREL/FRL, this issue was addressed applying the following steps of estimations (noting that figures have been rounded to the nearest whole number):

d. The emissions from forest degradation based on changes among land/forest strata (i.e. DG1 + DG2 + DG3 + DG) = 18,140,827 tCO2e/year.
e. The emissions from forest degradation based on changes among forest strata within the stratum (i.e. DG1 + DG2 + DG3) = 238,819 tCO2e/year.
f. The emissions from selective logging (included in SF1, SF2, SF3, DG1, DG2, DG3) = 8,146,058 tCO2e/year.

   The total emissions from forest degradation is therefore 26,048,065 tCO2e/year
   (18,140,827 (a) – 238,819 (b)) + 8,146,058 (c) = 26,048,065 tCO2e/year

4.5. Result of emissions and removals for FREL/FRL and MRV calculation

Related spread sheet in this section.

- Annex1 Sheet ⑥
- Annex2 Sheet ⑥

As the result, the emissions and removals for the period 2005-2010 and 2010-2014 per sources and sinks, and its total over the entire reference period (2005-2014) is as summarized in Table 11 below.

Table 11: Average Annual Historical Emissions and Removals over the Reference period (2005-2014)

Source/Sink	Emissions(+)/ Removals(-)		
	2005-2010 (tCO2e)	2010-2014 (tCO2e)	Annual average for 2005-2014 (tCO2e/year)
Deforestation	57,616,664	62,351,723	11,996,839
Forest Degradation	153,432,727	136,732,050	29,016,478
Changes among land/forest strata	98,311,948	99,984,864	19,829,681
Selective logging	55,120,779	36,747,186	9,186,797
Reforestation	-17,532,039	-14,956,818	-3,248,886
Restoration	-18,236,927	-24,609,792	-4,284,672
Total Emissions	211,049,391	199,083,773	41,013,316
Total Removals	-35,768,966	-39,566,610	-7,533,558

From the above, average value for each period was estimated in order to derive the annual historical emissions and removals. The results are show in Table 12 below.

Table 12: Annual historical emissions and removals by sources and sinks (2005-2014)

Year	Annual historical emissions and removals by sources and sinks				Reference level (tCO2e/yr)	
	Emissions: Deforestation	Emissions: Forest Degradation	Removals: Reforestation	Removals: Restoration	Emissions	Removals
2005	9,602,777	25,572,121	-2,922,006	-3,039,488	35,174,898	-5,961,494
2006	9,602,777	25,572,121	-2,922,006	-3,039,488	35,174,898	-5,961,494
2007	9,602,777	25,572,121	-2,922,006	-3,039,488	35,174,898	-5,961,494
2008	9,602,777	25,572,121	-2,922,006	-3,039,488	35,174,898	-5,961,494
2009	9,602,777	25,572,121	-2,922,006	-3,039,488	35,174,898	-5,961,494
2010	9,602,777	25,572,121	-2,922,006	-3,039,488	35,174,898	-5,961,494
2011	15,587,931	34,183,013	-3,739,205	-6,152,448	49,770,943	-9,891,653
2012	15,587,931	34,183,013	-3,739,205	-6,152,448	49,770,943	-9,891,653
2013	15,587,931	34,183,013	-3,739,205	-6,152,448	49,770,943	-9,891,653
2014	15,587,931	34,183,013	-3,739,205	-6,152,448	49,770,943	-9,891,653
				Average	41,013,316	-7,533,558

In conclusion, the FREL/FRL for Lao PDR is 41,013,316 tCO2e/year for the emissions and 7,533,558 tCO2e/year for the removals as shown in Table 13.

Table 13: Emissions and Removals for Lao PDR (2005-2014)

Emissions/Removals	tCO2e/year
Average historical emissions	+41,013,316
Average historical removals	--7,533,558

On the other hand, The emissions and removals for the period 2015-2018 are as summarized in Table 14 below.

Table 14: Average Annual Emissions and Removals over the MRV period (2015-2018)

Source/Sink	Emissions(+)/ Removals(-)		
	2015-2018 (tCO2)	Average annual 2015-2016 (tCO2e/year)	Average annual 2017-2018 (tCO2e/year)
Deforestation	44,974,274	11,243,569	11,243,569
Forest Degradation	106,273,739	27,088,804	26,048,065
Other than logging	71,608,030	17,902,008	17,902,008
Logging	34,665,708	9,186,797	8,146,058
Reforestation	-4,337,947	-1,084,487	-1,084,487
Restoration	-27,669,584	-6,917,396	-6,917,396
Total Emission	**151,248,013**	38,332,373	37,291,634
Total Removals	**-32,007,531**	-8,001,883	-8,001,883

From the above, average value for each period was estimated in order to derive the annual historical emissions and removals. The results are show in Table 12 below.

Table 15: Annual historical emissions and removals by sources and sinks (2015-2018)

Average annual historical emissions by sources and sinks						
Year	Emissions: Deforestation	Emissions: Forest Degradation	Removals: Reforestation	Removals: Restoration	Average annual (tCO2e/yr)	
					Emissions	Removals
2015[17]	11,243,569	27,088,804	-1,084,487	-6,917,396	38,332,373	-8,001,883
2016	11,243,569	27,088,804	-1,084,487	-6,917,396	38,332,373	-8,001,883
2017	11,243,569	26,048,065	-1,084,487	-6,917,396	37,291,634	-8,001,883
2018	11,243,569	26,048,065	-1,084,487	-6,917,396	37,291,634	-8,001,883

Table 16: Emissions and Removals for Lao PDR over the MRV period (2015-2018)

Emissions/Removals	tCO2e/year
Average historical emissions 2015-2016	38,332,373
2017-2018	37,291,634
Average historical removals 2015-2016	-8,001,883
2017-2018	-8,001,883

[17] As the 2nd NFI in fact includes tree stumps of 2015 and 2016, emissions from selective logging accounted in the FREL/FRL (i.e. 9,186,797 tCO2e/year) is also accounted as the emissions from selective logging for the 2015-2016 period. For the 2017-2018 period, tree stump data from the 3rd NFI is used to estimate the emissions from selective logging (i.e. 8,146, 058 tCO2e/year).

5. SOP Result calculation

Related spread sheet in this section.

- Annex1 Sheet ⑥
- Annex2 Sheet ⑥

From the section 4, average value for each period was estimated in order to derive the annual historical emissions and removals. The results are shown in Table 17 below.

Table 17: 1st National REDD+ Results - annual

Unit: tCO2e/year

	Year	Annual historical emissions and removals 2005-2015		Annual emissions and removals 2015-2018		1st National REDD+ Results 2015-2018	
		Emissions: Deforestation and Forest Degradation	Removals: Reforestation and Restoration	Emissions: Deforestation and Forest Degradation	Removals: Reforestation and Restoration	Emissions reduction	Removals increase
Reference period	2005	41,013,316	-7,533,558				
	2006	41,013,316	-7,533,558				
	2007	41,013,316	-7,533,558				
	2008	41,013,316	-7,533,558				
	2009	41,013,316	-7,533,558				
	2010	41,013,316	-7,533,558				
	2011	41,013,316	-7,533,558				
	2012	41,013,316	-7,533,558				
	2013	41,013,316	-7,533,558				
	2014	41,013,316	-7,533,558				
Results period	2015	41,013,316	-7,533,558	38,332,373	-8,001,883	2,680,944	468,325
	2016	41,013,316	-7,533,558	38,332,373	-8,001,883	2,680,944	468,325
	2017	41,013,316	-7,533,558	37,291,634	-8,001,883	3,721,683	468,325
	2018	41,013,316	-7,533,558	37,291,634	-8,001,883	3,721,683	468,325
	Total					12,805,253	1,873,301

In conclusion, the 1st National REDD+ Results for Lao PDR for the period of 2015-2016 and 2017-2018 is 2,680,944 tCO2e/year and 3,721,683 tCO2e/year respectively (12,805,253 tCO2e over 4 years) for emissions and 468,325 tCO2e/year (1,873,301 tCO2e over 4 years) for removals as shown in Table 18.

Table 18: Proposed 1st National REDD+ Results for Lao PDR (2015-2018)

Emissions/Removals	tCO2e/year	4 years total
Average emissions reduction 2015-2016	2,680,944	12,805,253
2017-2018	3,721,683	
Average removals increase 2015-2016	468,325	1,873,301
2017-2018	468,325	

6. SOP Uncertainty calculation

6.1. Identification and assessment of sources of uncertainty

Uncertainty associated with AD and E/R factors is quantified by providing accuracy, confidence interval (95%), distribution error and propagation of error following the 2006 IPCC Guidelines for National GHG Inventory (Chapter 3). The quantification method applied is simple error propagation equations, since errors in data and methods are not considered large as defined in the IPCC Guideline.

The Sources and Sinks of emission and removals are:

- Emission from Deforestation (DF)
- Emission from Forest degradation (DG)
- Removals from Reforestation (RF)
- Removals from Restoration (RS)

Apart from the above, the uncertainty associated with selective logging is assessed.

6.2. Assessment of uncertainty of Activity Data (AD)

Related spread sheet in this section.

- Annex1 Sheet ①
- Annex2 Sheet ①

The sources of uncertainty of AD is the error from procedures for interpretation of land/forest classes. This is commonly associated with the quality of satellite data, interoperability of the different sensors, image processing, cartography and thematic standards, location and co-registration, the interpretation procedure itself and post-processing. See detail more Activity Data reports[18][19].

Errors are calculated following the good practices for assessing accuracy assessment of land change as recommended in Olofsson et al (2014)[20]. To employ this approach, the land use change classes were validated using Collect Earth[21]. The results are shown in the tables below:

Table 19: Map accuracy and uncertainty of Activity Data 2005 - 2010

Class	DF	DG	RF	RS	SF	SNF
AD uncertainty	23.8%	39.6%	36.3%	44.7%	2.0%	9.7%
User accuracy	73.3%	63.3%	70.0%	83.3%	94.0%	87.7%
Producer accuracy	81.5%	65.5%	70.0%	65.8%	96.9%	75.0%
Overall accuracy	90.6%					

[18] Lao People's Democratic Republic Forest Reference Emission Level and Forest Reference Level for REDD+ Results Payment under the UNFCCC, Annex 2 Emission/Removal Factors Report

[19] Lao People's Democratic Republic 1st National REDD+ Results Report for REDD+ Results Payment under the UNFCCC, Annex 2 Emission/Removal Factors Report

[20] Olofsson et. al., 2014.

[21] Details at: http://www.openforis.org/tools/collect-earth.html

Table 20: Map accuracy and uncertainty of Activity Data 2010 – 2015

Class	DF	DG	RF	RS	SF	SNF
AD uncertainty	26.9%	39.3%	40.1%	43.8%	2.2%	10.5%
User accuracy	83.3%	60.0%	60.0%	76.7%	93.9%	79.0%
Producer accuracy	71.4%	66.7%	64.3%	63.9%	95.0%	77.7%
Overall accuracy	86.9%					

Table 21: Map accuracy and uncertainty of Activity Data 2015 – 2019

Class	**DF**	**DG**	**RF**	**RS**	**SF**	**SNF**
AD uncertainty	**30.9%**	**38.5%**	**44.7%**	**26.6%**	**1.6%**	**9.4%**
User accuracy	**86.7%**	**80.0%**	**76.7%**	**76.7%**	**97.4%**	**82.8%**
Producer accuracy	**83.9%**	**72.7%**	**79.3%**	**88.5%**	**97.0%**	**84.2%**
Overall accuracy	**93.2%**					

6.3. Assessment of uncertainty of Emission/Removal (E/R) factors[22]

Related spread sheet in this section.

- Annex1 Sheet ④
- Annex2 Sheet ④

The IPCC GL 2006 for National Greenhouse Gas Inventories (Volume 1, Chapter 3), lists out eight broad causes of uncertainties: lack of completeness; model; lack of data; lack of representativeness of data; statistical random sampling error; measurement error; misreporting or misclassification; and missing data. Some cause of uncertainty (e.g. bias) may be difficult to identify and quantify. Accordingly, the causes of uncertainties for the E/R Factors and their application in the uncertainty assessment are summarized in Table 22 below.

For Lao PDR, the main parameters which cause uncertainty of E/R Factors are considered as follows:

1. Uncertainty of AGB originating from sampling error (2nd NFI data/3rd NFI data)
2. Uncertainty of AGB originating from biomass equation
3. Uncertainty of Root-to-Shoot ratios due to the use of IPCC default values (IPCC GL 2006)
4. Uncertainty of Carbon Fraction factor due to the use of IPCC default values (IPCC GL 2006)
5. Uncertainty of AGB originating from measurement error (QC of 2nd NFI/3rd NFI)

After the uncertainty of each parameter are assessed, following the 'propagation of error approach' and by using the generic equations given in the IPCC Guidelines 2006 (Equation 3.1 and 3.2), the steps below were undertaken:

a. Calculate the total uncertainty of carbon stock per land/forest classes;
b. Combine into five Strata by using weighted value based on area proportion;
c. Calculate the uncertainties of E/R factors (Table 22); and
d. Calculate the uncertainty of E/R factors per sources and sinks (Table 23 and

[22] See Annex 2: Emission/Removal Factors Report for details.

e. Table 25).

Table 22: Emission/Removal Factors Uncertainty for FREL/FRL

	Stratum 1 (EG)	Stratum 2 (MD/CF/MCB)	Stratum 3 (DD)	Stratum 4 (P/B/RV)	Stratum 5 (NF)
Stratum 1 (EG)		13.6%	15.6%	17.3%	18.2%
Stratum 2 (MD/CF/MCB)	13.6%		10.3%	11.9%	12.7%
Stratum 3 (DD)	15.6%	10.3%		13.3%	14.2%
Stratum 4 (P/B/RV)	17.3%	11.9%	13.3%		20.4%
Stratum 5 (NF)	18.2%	12.7%	14.2%	20.4%	

Table 23 Uncertainty of E/R factors per sources and sinks for FREL/FRL

	Uncertainty (%)
Deforestation	11.4%
Forest Degradation	7.4%
Reforestation	11.4%
Restoration	7.4%

Table 24: Emission/Removal Factors Uncertainty for MRV

	Stratum 1 (EG)	Stratum 2 (MD/CF/MCB)	Stratum 3 (DD)	Stratum 4 (P/B/RV)	Stratum 5 (NF)
Stratum 1 (EG)		**12.0%**	**13.3%**	**15.3%**	**15.7%**
Stratum 2 (MD/CF/MCB)	**12.0%**		**10.5%**	**12.5%**	**13.3%**
Stratum 3 (DD)	**13.3%**	**10.5%**		**13.2%**	**14.4%**
Stratum 4 (P/B/RV)	**15.3%**	**12.5%**	**13.2%**		**15.1%**
Stratum 5 (NF)	**15.7%**	**13.3%**	**14.4%**	**15.1%**	

Table 25 Uncertainty of E/R factors per sources and sinks for MRV

	Uncertainty (%)
Deforestation	10.1%
Forest Degradation	6.5%
Reforestation	10.1%
Restoration	6.5%

6.4. Quantification of uncertainty of emissions and removals for FREL/FRL and MRV

6.4.1. Uncertainty of the emissions and removals based on changes among five strata

Related spread sheet in this section.

- Annex1 Sheet ⑤
- Annex2 Sheet ⑤

Based on the uncertainty assessment of AD and E/R factors, the uncertainty of the emissions and removals through changes among the five strata is calculated per sources and sinks using propagation of error approach.

Estimation of total uncertainty

After the uncertainty of each parameter are assessed, the total uncertainty of carbon stock was calculated through 'propagation of error approach' and by using the following generic equations given in the IPCC GL 2006.

EQUATION 3.1
COMBINING UNCERTAINTIES – APPROACH 1 – MULTIPLICATION

$$U_{total} = \sqrt{U_1^2 + U_2^2 + ... + U_n^2}$$

Where:

U_{total} = the percentage uncertainty in the product of the quantities (half the 95 percent confidence interval divided by the total and expressed as a percentage);

U_i = the percentage uncertainties associated with each of the quantities.

Combining uncertainties is calculated by using above equation using uncertainty of AD and E/R factors. Table 26 and Table 27 show the results of the calculation, which are 19.6% for emissions and 19.3% for removals.

Table 26: Uncertainty of the emission level for 2005-2010 and 2010-2015 by sources/sinks –based on changes among five strata

Source/Sink	2005-2010			2010-2014		
	Amount (tCO_2e)	Uncertainty range (tCO_2e)	Uncertainty range (%)	Amount (tCO_2e)	Uncertainty range (tCO_2e)	Uncertainty range (%)
DF	57,616,664	15,187,469	26.4%	62,351,723	18,222,384	29.2%
DG	98,311,948	39,574,152	40.3%	99,984,864	39,989,415	40.0%
RF	-17,532,039	-6,676,905	38.1%	-14,956,818	-6,240,095	41.7%
RS	-18,236,927	-8,255,007	45.3%	-24,609,792	-7,865,393	32.0%

Table 27: Uncertainty of the reference level over the reference period – based on changes among five strata

Source/Sink	Per Sources and sinks (2005-2014)			Per Emission/removal (2005-2014)		
	Amount (tCO_2e/year)	Uncertainty range (tCO_2e/year)	Uncertainty range (%)	Amount (tCO_2e/year)	Uncertainty range (tCO_2e/year)	Uncertainty range (%)
DF	11,996,839	2,481,970	20.7%	31,826,520	6,252,988	19.6%
DG	19,829,681	5,739,310	28.9%			
RF	-3,248,886	-934,619	28.8%	-7,533,558	-1,457,714	19.3%
RS	-4,284,672	-1,118,667	26.1%			

On the other hand, uncertainty of the MRV is shown in the Table 28 which shows the results of the calculation, which are 27.1% for emissions and 24.5% for removals.

Table 28: Uncertainty of the MRV over the MRV period – based on changes among five strata

Source/Sink	Per Sources and sinks (2015-2018)			Per Emission/removal (2015-2018)		
	Amount (tCO_2e/year)	**Uncertainty range (tCO_2e/year)**	**Uncertainty range (%)**	**Amount (tCO_2e/year)**	**Uncertainty range (tCO_2e/year)**	**Uncertainty range (%)**
DF	11,243,569	3,660,107	32.6%	29,145,576	7,890,995	27.1%
DG	17,902,008	6,990,810	39.1%			
RF	-1,084,487	-497,007	45.8%	-8,001,883	-1,958,216	24.5%
RS	-6,917,396	-1,894,095	27.4%			

6.4.2. Uncertainty of emissions by selective logging

Related spread sheet in this section.

- Annex1 Sheet ⑧,⑨
- Annex2 Sheet ⑧,⑨

In addition, uncertainty of emissions from forest degradation by selective logging was assessed with the same propagation of error approach. Based on the method explained in Section 4.3, uncertainty of Forest Type Map 2015 and 2019 and uncertainty of E/R factors are used as the two parameters.

Table 29: Uncertainty of the Forest Type Map 2015 for the uncertainty assessment of emissions from selective logging

	Area(ha)	Uncertainty (%)
EG	2,605,557	6.7%
MDF	9,205,036	4.1%
CF	124,772	40.8%
MCB	107,880	35.9%
DD	1,188,198	12.7%

Table 30: Uncertainty of the Forest Type Map 2019 for the uncertainty assessment of emissions from selective logging

	Area(ha)	Uncertainty (%)
EG	2,594,961	3.7%
MDF	9,036,767	4.4%
CF	124,009	15.8%
MCB	106,848	0.0%
DD	1,171,873	10.3%

Table 31: Uncertainty of the E/R factors for the uncertainty assessment of emissions from selective logging for FREL/FRL

	Uncertainty					AGB+BGB Ave tCO2/ha	Uncertainty (%)
Forest class	①	②	③	④	⑤		
EG	14.0	30.0	11.5	2.7	10.0	17.8	36.5%
MD	5.0	30.0	11.5	2.7	10.0	4.8	34.1%
CF	13.2	30.0	20.3	2.7	10.0	2.7	39.9%
MCB	22.3	30.0	11.5	2.7	10.0	18.8	40.4%
DD	8.7	30.0	11.5	2.7	10.0	14.3	34.8%

1. Uncertainty of AGB originating from sampling error (2nd NFI data): same with the E/R factors.
2. Uncertainty of AGB originating from biomass equation: expert judgement for applications of stump-to-DBH model from Cambodia, and uncertainty of the E/R factors (3.6-18.0 for the forest classes in subject)
3. Uncertainty of Root-to-Shoot ratios, due to the use of IPCC default values (IPCC GL 2006): same with E/R factors.
4. Uncertainty of Carbon Fraction factor, due to the use of IPCC default values (IPCC GL 2006): same with E/R factors.
5. Uncertainty of AGB originating from measurement error (QC of 2nd NFI): expert judgement for uncertainty of the E/R factors (3.1-8.7%)

Table 32: Uncertainty of the E/R factors for the uncertainty assessment of emissions from selective logging for MRV

	Uncertainty					AGB+BGB Ave tCO2/ha	Uncertainty (%)
Forest class	①	②	③	④	⑤		
EG	10.2	30.0	11.5	2.7	10.0	11.4	35.3%
MD	4.8	30.0	11.5	2.7	10.0	5.8	34.1%
CF	11.1	30.0	20.3	2.7	10.0	13.1	39.3%
MCB	14.1	30.0	11.5	2.7	10.0	9.0	36.6%
DD	8.2	30.0	11.5	2.7	10.0	11.6	34.7%

Note: refer to the note of previous table

Uncertainty of each class (5 natural forest classes) is estimated by using Equation 3.1 of IPCC GL 2006

Uncertainty of emission from selective logging described as total uncertainty in the following tables is estimated by using Equation 3.2 of IPCC GL 2006.

EQUATION 3.2
COMBINING UNCERTAINTIES – APPROACH 1 – ADDITION AND SUBTRACTION

$$U_{total} = \frac{\sqrt{(U_1 \bullet x_1)^2 + (U_2 \bullet x_2)^2 + \ldots + (U_n \bullet x_n)^2}}{|x_1 + x_2 + \ldots + x_n|}$$

Where:

U_{total} = the percentage uncertainty in the sum of the quantities (half the 95 percent confidence interval divided by the total (i.e., mean) and expressed as a percentage). This term 'uncertainty' is thus based upon the 95 percent confidence interval;

x_i and U_i = the uncertain quantities and the percentage uncertainties associated with them, respectively.

The resulting uncertainty is estimated as 21.7% for FREL/FRL period and 21.8 % for MRV period as show in the table below[23].

Table 33: Estimated emissions for degradation from selective logging for FREL/FRL period

	Emissions (tCO2e)	Uncertainty (%)
EG	46,353,989	37.1%
MDF	44,531,308	34.4%
CF	336,245	57.1%
MCB	2,024,360	54.0%
DD	16,995,658	37.1%
Total	**110,241,559**	**21.7%**

Table 34: Estimated emissions for degradation from selective logging for MRV period

	Emissions (tCO2e)	Uncertainty (%)
EG	29,646,105	35.5%
MDF	51,974,068	34.4%
CF	1,626,038	42.4%
MCB	965,339	36.6%
DD	13,541,141	36.2%
Total	**97,752,691**	**21.8%**

6.4.3. Estimation of overall uncertainty

Related spread sheet in this section.

- Annex1 Sheet ⑥
- Annex2 Sheet ⑥

[23] However, this level of uncertainty does not include potential uncertainties contained in the applied method, namely the use of biomass decay model developed in Malaysia. As this is difficult quantify objectively, it is not included in the current assessment.

The uncertainty of emission including selective logging and removals described as total uncertainty in the following tables is estimated by using Equation 3.2 of IPCC GL 2006

As the final result, the overall uncertainty of the FREL/FRL is considered as 16.7% for emissions and 19.3% for removals.

Table 35: Overall uncertainty of the FREL/FRL

Source/Sink	2005-2015		
	Amount tCO2e/year	Uncertainty range tCO2e/year	Uncertainty %
Emissions (5 strata and selective logging combined)	41,013,316	6,562,648	16.0%
Removals	-7,533,558	-1,457,714	19.3%

The uncertainty of the emissions excluding logging, and uncertainty for the removals for the period 2015-2018 are as summarized in Table 36 below.

Table 36: Estimated uncertainty of the emissions excluding logging and removals

Source/Sink	2015-2018		
	Amount tCO2e/year	Uncertainty range tCO2e/year	Uncertainty range %
Emissions	29,145,576	7,890,995	27.1%
Removals	-8,001,883	-1,958,216	24.5%

The uncertainty of the emissions from selective logging for the period 2017-2018 is as summarized in Table 37 below.

Table 37: Estimated uncertainty of the emissions from selective logging

Source/Sink	2017-2018		
	Amount tCO2e/year	Uncertainty range tCO2e/year	Uncertainty range %
Emissions from selective logging	8,146,058	1,776,135	21.8%

6.5. Uncertainty of Result

Related spread sheet in this section.

- Annex1 Sheet ⑥
- Annex2 Sheet ⑥

The overall uncertainty of the 1st National REDD+ Results was calculated also through 'propagation of error approach' by using Equation 3.2 of IPCC GL 2006.

As the final result, the overall uncertainty of the proposed 1st National REDD+ Results is considered as 16.5% for emissions and 15.7% for removals for the 2015-2016 period, and 12.7% for emissions and 15.7% for removals for the 2017-2018 period.

Table 38: Overall uncertainty of the proposed 1st National REDD+ Results (2015-2016)

Source/Sink	2015-2016		
	Amount tCO2e/year	Uncertainty range tCO2e/year	Uncertainty %
Emission s	2,680,944	442,697	16.5%
Removals	468,325	73,592	15.7%

Table 39: Overall uncertainty of the proposed 1st National REDD+ Results (2017-2018)

Source/Sink	2017-2018		
	Amount tCO2e/year	Uncertainty range tCO2e/year	Uncertainty %
Emissions	3,721,683	470,809	12.7%
Removals	468,325	73,592	15.7%

7. Annex

Spread sheet for estimation

Annex 1. National_REL+UncertaintyAssessment.xlsx

Annex 2. National_MRV+UncertaintyAssessment.xlsx

Annex 3. StumpAnalysis_REL.xlsx

Annex 4. StumpAnalysis_MRV.xlsx