# Lao People's Democratic Republic Forest Reference Emission Level and Forest Reference Level for REDD+ Results Payment under the UNFCCC

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Department of Forestry

Ministry of Agriculture and Forestry, Lao PDR

# **Table of Contents**

1.	FO	REST DEFINITION	1
2.	LAI	ND AND FOREST CLASSIFICATION AND STRATIFICATION SYSTEMS	3
2	.1.	Land and forest classification system	3
2	.2.	Stratification	5
3.	ELE	EMENTS FOR FREL/FRL	7
3	.1.	Activities	7
3	.2.	Carbon Pools	8
3	.3.	Gases	9
3	.4.	Scale	10
3	.5.	Reference period	10
4.	СО	NSTRUCTION OF THE FREL/FRL	. 12
4	.1.	Background context and method of construction	. 12
		4.1.1. National circumstances and adjustments	. 12
		4.1.2. General methodologies	13
4	.2.	Historical data used for the construction of the FREL/FRL	. 15
		4.2.1. Activity Data	15
		4.2.2. Emission and Removal Factors	. 18
		4.2.3. Supplementary analysis of the impact of selective logging	19
4	.3.	Calculation of the FREL/FRL	22
		4.3.1. Emission and removals calculated based on changes among land/forest strata	ı 22
		4.3.2. Emissions from selective logging (degradation)	25
		4.3.3. Results of calculation	25
5.	AS:	SESSMENT OF UNCERTAINTY	28
5	.1.	Identification and assessment of sources of uncertainty	. 28
5	.2.	Assessment of uncertainty of Activity Data (AD)	. 28
5	.3.	Assessment of uncertainty of Emission/Removal factors	29
5	.4.	Ouantification of uncertainty in FREL/FRL setting	. 30

		5.4.1. Uncertainty of the emissions and removals based on changes among 5 REDD strata	
	!	5.4.2. Uncertainty of emissions by selective logging	31
		5.4.3. Estimation of overall uncertainty	32
6	. TRA	ANSPARENCY AND DATA NECESSARY FOR THE RECONSTRUCTION OF FREL/FRL	33
7	. ISSI	UES FOR FUTURE FREL/FRL AND MRV	34
	7.1.	Issues for future improvement	34
	7.2.	Consistency with national GHG-Inventory	36

Annex 1: Activity Data Report

Annex 2: Emission/Removal Factors Report

# **List of Tables**

Table 1: Summary of the definition of "Current Forest" and "Potential Forest" of Lao PD	)R 1
Table 2: National level land and forest classification system of Lao PDR with IPCC definition on land use categories	3
Table 3: Stratified land/forest classification system and the five land/forest strata	5
Table 4: REDD+ activities included in the FREL/FRL	7
Table 5: Carbon pools accounted for in the FREL/FRL	8
Table 6: Gases accounted for in the FREL/FRL	9
Table 7: Resolution of the satellite imagery used for the Forest Type Map development	11
Table 8: National-level drivers and intervention programs	. 12
Table 9: Details of the satellite imagery used for the development of Forest Type Maps	. 15
Table 10: Area by five land/forest strata	. 16
Table 11: Activity data 2005 – 2010	. 17
Table 12: Activity data 2010 – 2015	. 17
Table 13: Carbon stock of the five strata	. 19
Table 14: Emissions/Removals Factors for changes (tCO2e)	. 19
Table 15: Loss of material weights over years based on temperature	. 21
Table 16: Temperature and precipitation in Lao PDR (2014) and Pasoh (study site)	. 21
Table 17: Typologies of change for removals	. 22
Table 18: Over-estimated removals tracked	. 23
Table 19: Tracked over-estimation of emissions	. 24
Table 20: Comparison of before and after adjustment	. 24
Table 21: Historical Emissions and Removals – based on changes among land/forest stra	
Table 21: Estimated total emissions from selective logging	. 25
Table 23: Average Annual Historical Emissions and Removals over the Reference period	l 27
Table 24: Annual historical emissions and removals by sources and sinks	. 27
Table 25: Proposed reference emissions and removals for Lao PDR (2005-2015)	. 27
Table 26: Map accuracy and uncertainty of Activity Data 2005 - 2010	. 28
Table 27: Man accuracy and uncertainty of Activity Data 2010 – 2015	28

	Table 28: Emission/Removal Factors Uncertainty	29
	Table 29 Uncertainty of E/R factors per sources and sinks	30
	Table 30: Uncertainty of the emission level for 2005-2010 and 2010-2015 by sources/sin —based on changes among 5 REDD+ strata	
	Table 31: Uncertainty of the reference level over the reference period – based on change among 5 REDD+ strata	
	Table 32: Uncertainty of the Foerst Type Map 2015 for the uncertainty assessment of emissions from selective logging	31
	Table 33: Uncertainty of the E/R factors for the uncertainty assessment of emissions from selective logging	
	Table 34: Estimated emissions for degradation from selective logging	32
	Table 35: Overall uncertainty of the proposed FREL/FRL	32
	Table 36: Data to be presented in the NFMS web-portal	33
	Table 37: Summary of plan for the NC and BUR	36
List	of Figures	
	Figure 1: Slash-and-burn cycle and land/forest classes	. 4
	Figure 2: Outline workflow of developing the Forest Type Maps	16
	Figure 3: Relative values of material weights over years	21
	Figure 4: Annotated change matrix among land/forest strata for addressing double-counting in degradation	26
List	of Boxes	
	Box 1: Lands under shifting cultivation	. 4

#### **Acronyms**

AE Allometric Equation
AGB Above Ground Biomass

B Bamboo

BGB Below Ground Biomass CF Coniferous Forest

DBH Diameter at Breast Height
DD Dry Dipterocarp Forest
DOF Department of Forestry

DW Dead Wood EG Evergreen Forest

E/R factors Emission and Removal Factor

FIPD Forestry Inventory and Planning Division

FREL Forest Reference Emission Level

FRL Forest Reference Level

GHG Greenhouse Gas

GIS Geographic Information System

IPCC Intergovernmental Panel on Climate Change

Lao PDR Lao People's Democratic Republic
MAF Ministry of Agriculture and Forestry
MCB Mixed Coniferous Broadleaved Forest

MD Mixed Deciduous Forest
NFI National forest Inventory

NFMS National Forest Monitoring System

P Plantation

REDD+ Reducing Emissions from Deforestation and forest Degradation plus the

conservation of forest carbon stocks, sustainable management of forests and

enhancement of forest carbon stocks

FREL/FRL Forest Reference Emission level/Forest Reference Level

RV Regenerating Vegetation
StD Standard Deviation
StE Standard errors
UC Upland Crop

UNFCCC United Nations Framework Convention on Climate Change

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#### 1. FOREST DEFINITION

According to the Land Law (2003) and Forestry Law (2007), forest and forest resources in Lao PDR occur in lands that are designated by the Government as forest lands, and in areas outside forest lands, and includes both stocked and temporarily un-stocked forests.

The land and forest classification system of the country applies two levels of classification, namely, Level 1 consisting of seven classes including "Current Forests" and "Potential Forests" among others, and Level 2 which further classifies the "Current Forest" class under Level 1 into five natural forest and one plantation forest classes. The land classification system is illustrated in Table 2 below. The carbon accounting approach applied in the national FREL/FRL uses both "Current Forest" and "Potential Forest" classes as corresponding to the IPCC forestland category.

Lao PDR applies a definition for Current and Potential forests respectively, for which a summary is shown in the following Table 1.

Table 1: Summary of the definition of "Current Forest" and "Potential Forest" of Lao PDR

Current Forest	Potential Forest		
Stand DBH: minimum of 10cm Crown density: minimum of 20% Minimum area of 0.5ha.	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, and not permanently being used for other purposes (i.e. residential, agriculture etc.). It also does not include Upland Crop (UC), despite its common nature as a cropping stage of shifting cultivation cycle, based on de facto land-use at the time of observation		

Note: The main reason of applying the DBH threshold for the "Current Forest" definition, over the more conventional height threshold is to facilitate the accounting of forest fallow, typically classified as Regenerating Vegetation (RV), as Potential Forest (and not Current Forest). Such regenerating forests are often covered by small diameter trees over 5.0m in height. In the context of the country, such lands should not be considered as Current Forest because repeated disturbance may maintain such land in an understocked condition for an indeterminate period of time, and therefore, are better managed when classified as Potential Forests. By applying the definition of a minimum stand DBH of 10 cm<sup>1</sup>, forest land covered with small diameter trees which would have been classified as "Current Forest" under a height threshold definition can be excluded from the NFI survey measurements. Also note that the DBH criteria applies to the trees to be measured during the NFI. Thereby, where there are no trees meeting this criterion, the NFI measurements would not be applied.

The main reason for the 20% crown density threshold for the "Current Forest" definition is to do with the national circumstances of trees commonly occurring in rice paddy landscapes in the flatland areas. In order to avoid misinterpretation of these paddy lands as forests, particularly through remote sensing – as such lands often have canopy cover of over 10% – the 20% crown density threshold has been adopted, for Current Forests.

"Current Forest" consists of forest with trees with minimum DBH of 10cm forming minimum crown density of 20% and constituting a minimum area of 0.5ha.

"Potential Forest" is 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"

<sup>&</sup>lt;sup>1</sup> Experience of experts at DOF generally agree on DBH having a higher correlation with crown cover compared to that with height.

status if continuously left undisturbed. This definition is in line with the IPCC's definition of forest land which includes "...a vegetation structure that currently fall below, but *in situ* could potentially reach the threshold values used by a country to define the Forest Land category..." (IPCC, 2006). In Lao PDR, over 98% of the "Potential Forest" is composed of the Regenerating Vegetation (RV) class, with the remaining being in the Bamboo class. Due to lack of time-series land-use/cover data with higher observation frequency, these two classes are classified as "Potential Forest" in each forest mapping cycle, regardless of their historical land-use/cover. Although Upland Crop (UC) is, in most cases, understood as one stage of shifting cultivation, it is classified under Crop Land and not considered as "Potential Forest" based on the de facto land-use at the time of observation.

This same forest definition was used also in the past two National Communications on Climate Change, submitted to the UNFCCC. Nationally, decisions have already been taken to also employ the same definition into the future in compiling the national GHG inventory starting with the Third National Communication which the Government plans to submit to the UNFCCC in early 2019<sup>2</sup>.

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<sup>&</sup>lt;sup>2</sup> This definition is different from what Lao PDR used for the reporting to the FAO Forest Resources Assessment (FRA) 2015. In FAO-FRA 2015, Lao PDR defines "forest" as: minimum height of trees of 5.0 m; minimum forest canopy cover of 10%; and minimum area of 0.5ha.

#### 2. LAND AND FOREST CLASSIFICATION AND STRATIFICATION SYSTEMS

#### 2.1. Land and forest classification system

The land and forest classification system of the country applies two levels of classification, namely, Level 1 consisting of seven classes including "Current Forest" and "Potential Forest" among others, and Level 2 which further classifies "Current forest" class under Level 1 into six natural and plantation forest classes. The land classification system is illustrated in Table 2 below, and a full description of the definition of each Level 2 class is available at the Department of Forestry (DOF)'s website<sup>3</sup>.

Around 2010, when Lao PDR initiated the development of its national Forest Type Maps (Forest Type Maps: wall-to-wall maps of the entire territory) to support REDD+, the government and the stakeholders, first, reviewed the land/forest classification system to be applied for the mapping exercise.

Table 2: National level land and forest classification system of Lao PDR with IPCC definition on land use categories

d use categories					
IPCC Definition	National level classification system				
IPCC Definition	Level 1	Level 2			
Forest Land	Current Forest	Evergreen Forest	EG		
		Mixed Deciduous Forest	MD		
		Dry Dipterocarp Forest	DD		
		Coniferous Forest	CF		
		Mixed Coniferous and Broadleaved Forest	MCB		
		Forest Plantation	Р		
	Potential Forest	Bamboo	В		
		Regenerating Vegetation	RV		
Grassland	Other Vegetated Areas	Savannah			
		Scrub	SR		
		Grassland	G		
Cropland	Cropland	Upland Crop			
		Rice Paddy	RP		
		Other Agriculture	OA		
		Agriculture Plantation	AP		
Settlement	Settlement	Urban Areas	U		
Other land	Other land		BR		
		Other Land	0		
Wetland	Vetland Above-ground Water River (Water)		W		
	Source	Wetland (Swamp)	SW		

An important point was to ensure the classification system was in harmony with the land-use category definition of the IPCC in order to maintain consistency between the REDD+ FREL/FRL and MRV and the National Greenhouse Gas (GHG) Inventory. Another was to determine how to categorize the temporarily un-stocked forests in the classification system (i.e. "regenerating vegetation: RV"). This reflects the unique situation of forests and forest use in the country, and in

<sup>&</sup>lt;sup>3</sup> http://dof.maf.gov.la/en/home/

particular, the prevalence of shifting cultivation, and presence of vast areas of forest fallow. This land-use is seen throughout the country where a significant area is covered under forest fallow stages of shifting cultivation, regenerating through natural vegetative succession, going in and out (currently only in limited cases) of temporarily un-stocked states. Restoration of RV into the forest state has been a high priority agenda of the Government as stated in the 8<sup>th</sup> National Socio-Economic Development Plan.

#### Box 1: Lands under shifting cultivation

Of the above land/forest classes, UC (upland crops) and RV (forest fallow) classes are for the most part considered to be stages of the shifting cultivation cycle, and these lands can re-grow and recover into stocked forest (mostly to Mixed Deciduous Forest (MD)) through natural vegetative succession. Through intensive discussions within the DOF and with stakeholders on whether to classify these under the IPCC land use category of "Forest Land" or "Cropland", it was concluded that, in line with the IPCC definition, to classify RV as Forest Land as they are "...a vegetation structure that currently fall below, but in situ could potentially reach the threshold values used by a country to define the Forest Land category..." (IPCC, 2006) and classify UC as "Cropland" as they are used, even temporarily, for cropping at the time of mapping.

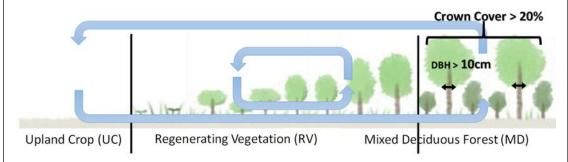


Figure 1: Slash-and-burn cycle and land/forest classes

Lao PDR recognizes that by applying such method of classification, a piece of land not undergoing land use change, but, only temporary land cover change (i.e. short-term changes) would be subject to designation as undergoing a change event. However, Lao PDR choses to apply this method for the REDD+ FRL/FREL and MRV. The strong rationale for this decision is the Government's commitment to its agenda of stabilizing the shifting cultivation landscape and increasing forest cover to 70%. The estimation of change resulting from method of classification is consistently and symmetrically conducted for emissions and removals. For example, when a shifting cultivation landscape undergoes change from RV (forest fallow) to UC (upland crop) this short-term loss is recorded; on the other hand, when the UC is left for fallow and regenerates into RV, this removal is also recorded; meaning that estimation of emissions is offset by estimation of removals, so far as the rotational agricultural practice continues.

It should be also noted that distinguishing RV and MD classes which are continuous phases of regeneration in many cases, poses a technical challenge in remote sensing<sup>4</sup>. To improve the accuracy

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<sup>&</sup>lt;sup>4</sup> Similar to the case when applying a height threshold, the DBH threshold cannot be applied through remote sensing. However, knowing the challenges of distinguishing RV and MD in forest mapping, several efforts were made. For example, larger number of ground-truthing points were given to the two classes, particularly to ambiguous polygons. The DBH > 10cm threshold was applied at the ground-truthing and the results were reflected into the interpretation process afterwards. Ancillary information, such as topography, land-use in neighboring land-plots, shape/size of the land-plot, proximity to village areas, were also used.

For generation of EF, the DBH criterion is applied in the biomass survey (2nd NFI), by only measuring the forest plots which meet the definition of "Current Forest" including the DBH threshold criteria.

Lao PDR acknowledges the potential for discrepancies between the "Current Forest" captured in forest mapping and in the biomass survey. However, it should be noted that this is a fairly common issue due to the technical constraint of remote sensing, even when applying a height threshold criteria.

of classification, the initial classification of satellite imagery was further reviewed and revised by applying the '8 years threshold' as the standard number of years for forest regeneration after a forest plot is slashed and burnt. Based on this method, MD plots where vegetation loss was confirmed in the past one to eight years, identified in annual vegetation loss dataset by Hansen et al (2013), were revised to RV with an assumption that land will not regenerate into MD class in less than 8 years. This made the mapping of MD area conservative, and thereby making emissions/removals estimate conservative. See Annex 1: Activity Data Report for further details.

#### 2.2. Stratification

For the purpose of the REDD+ MRV, the national land and forest classification explained in Section 2.1 are condensed into five strata. Such simplified stratification will help reduce uncertainty of emissions and removals while balancing the accuracy of sampling and the cost/efforts required. The forest stratification used for the construction of the FREL/FRL includes the following five types of forest land and non-forest land as shown in Table 3:

- Evergreen Forest (EG) has distinctly high carbon stocks (200.0tC), thus, separated as an independent stratum Stratum 1 (expanse: 2,605,557ha, 11.3% of the total land area).
- Mix Deciduous Forest (MD), Conifer Forest (CF) and Mixed Coniferous and Broadleaved Forest (MCB) will form one stratum on the basis of similarity in carbon stocks per hectare (87.7tC, 92.6tC, 114.7tc). – Stratum 2 (expanse: 9,437,688ha, 40.9% of the total land area).
- Dry Dipterocarp Forest (DD) will form one stratum due to the difference in carbon stock from other forest classes (43.2tC), and also due to the fact that they are mostly distributed in the low-lands and prone to conversion to other land use – Stratum 3 (expanse: 1,188,198ha, 5.2% of the total land area).
- Plantation (P), Bamboo (B) and Regenerating Vegetation (RV) will form one stratum on the basis of similarity in average carbon stock (37.2tC, 24.4tC, 17.4tC) Stratum 4 (expanse: 6,300,445ha, 27.3% of the total land area).
- The remaining 12 non-forest classes will form one stratum Stratum 5 (expanse: 3,522,370ha, 15.3% of the total land area).

Table 3: Stratified land/forest classification system and the five land/forest strata

Land/	Area (ha)	% of total area	Strata		
Level 1	Level 2				
	Evergreen Forest	EG	2,605,557	11.3%	1
	Mixed Deciduous Forest	MD	9,437,688		
	Coniferous Forest	CF		40.9%	2
Current Forest	Mixed Coniferous and Broadleaved Forest	МСВ	3,437,086 40.3%		2
	Dry Dipterocarp Forest	DD	1,188,198	5.2%	3
	Forest Plantation	Р			
	Bamboo	В	6,300,445	27.3%	4
Potential Forest	Regenerating Vegetation	RV	0,300,445 27.3%		4

	Savannah	SA				
Other Vegetated Areas	Scrub	SR				
	Grassland	G				
	Upland Crop	UC				
Cronland	Rice Paddy	RP	3,522,370 15.3%			
Cropland	Other Agriculture	OA		15 20/	5	
	Agriculture Plantation	AP		15.5%		
Settlement	Urban Areas	U				
Other Land	Barren Land and Rock	BR				
Other Land	Other Land	0				
Above-ground Water	Wetland (Swamp)	SW				
Source	River (Water)	W				
Total			23,054,258	100%		

Lao PDR acknowledges that this stratification deviates from IPCC guidelines, in that the emissions and removals are not estimated according to the IPCC land-use categories. In fact, Lao PDR have data to enable estimation according to the IPCC land-use categories. However Lao PDR considered the current approach reasonable due to the reasons below:

- As both Current Forest and Protection Forest are considered to constitute the IPCC Forest Land category, totally composing nearly 85% of the national territory, and 11% within the 15% of the remaining non-Forest Land area is under Cropland;
- Dividing the limited area of non-Forest Land area into Grassland, Cropland, Settlement,
  Other land and Wetland would lead to complexity in the analysis, estimation of AD and
  assessment of uncertainty. The complexity in turn may inject additional uncertainty in the
  results, while it would make little difference in the estimate of FREL/FRL, considering the
  dominance of Cropland;
- Using an average biomass for non-Forest Land taken from the IPCC defaults and calculated with a weighted average (see Annex 2: Emission/Removal Factors Report) can be seen as a reasonable simplification to avoid additional uncertainty.
- Consequential differences with the GHG-Inventory (expected to apply IPCC land-use categories) can be explained if necessary, but only after Lao PDR submits its next GHG-Inventory.

## 3. ELEMENTS FOR FREL/FRL

#### 3.1. Activities

The REDD+ activities applied under the FREL/FRL of Lao PDR are as follows;

Table 4: REDD+ activities included in the FREL/FRL

Activities	Included?	Justification / Explanation
Emissions from deforestation	Yes	A deforestation event is a change of a forest land stratum to a non-forest land stratum.  This can be caused by activities such as conversion of forests to agricultural land, infrastructure, urbanization, etc.  The total emissions from deforestation account for approximately 34%
		of all forest-related emissions in the reference period (2005-2015).
Emissions from forest degradation	biomass stratum to lower biomass stratum, and also to measurement of tree stumps as a proxy indicator of logging a (see Section4.2.3).  This can be caused by activities such as selective logging. The evolution conversion of natural forest to forest plantation is also by define degradation event. The short-term changes between certain strotational agriculture may also be recorded as a degradation event degradation events occur most often in Evergreen forests (Strata).	
		and Mixed Deciduous forests (Stratum 2) being degraded into RV (Stratum 4).  The total emissions from forest degradation account for approximately 66% of all forest-related emissions in the reference period (2005-2015).
Removals from forest enhancement (Restoration)	Yes	A restoration event is a change within forest land stratum from a lower biomass stratum to a higher biomass stratum (in IPCC terms, "forest land remaining forest land").  This is often a result of regrowth of the RV (Stratum 4) to other natural forest classes.
Removals from forest enhancement (Reforestation)	Yes	A reforestation event is a change of non-forest stratum (Stratum 5) to forest land strata (Strata 1-4).  This is often a result of a non-forest land (Stratum 5) being converted into the Plantation class, or regenerating into the RV (both Stratum 4).
Emissions and Removals from conservation of carbon stock	No	There is no national definition for this REDD+ activity.
Emissions and Removals from sustainable management of forests	No	There is no national definition for this REDD+ activity.  However, there is a comprehensive accounting for GHG emissions and removals from forests so GHG emissions and removals that could potentially be included in this activity are included in the other REDD+ activities.

<sup>&</sup>lt;sup>5</sup> Lao PDR acknowledges that as per UNFCCC Decision 1/CP.16, Appendix 1, Section 2(e), conversion of natural forests into forest plantations should not be considered as a REDD+ activity. However, there is a high interest in the forestry sector to promote sustainable plantation development. Lao PDR intends to consult this issue with the UNFCCC, and reflect the conclusions in the MRV. Note that the MRV will use geographically explicit data to allow identification of such areas.

In Lao PDR's carbon accounting, all the emissions from deforestation and forest degradation are regarded as anthropogenic, for the reason that, forests in the country are home to many different mountain ethnic groups in and interacting with the forests in their daily lives; and large-scale natural disasters in forest areas or forest diseases are not common. In addition there is no suitable technology yet to clearly distinguish anthropogenic and non-anthropogenic emissions.

In the future, Lao PDR may include emissions from degradation occurring in forests remaining in the same category (e.g. firewood, disturbance). This is not currently accounted for due to lack of robust nationally-derived datasets, except for the emission from selective logging estimated through measurement of tree stumps as a proxy indicator. It is expected that the 3rd NFI planned for the 2018/2019 dry season will enable measurement of such changes.

For the same reason, in the future, Lao PDR may also include removals through forest restoration as a result of improved management of RV and forests remaining in the same category, but with an increased average carbon stock (e.g. growth in living biomass pools)<sup>6</sup>.

#### 3.2. Carbon Pools

The following table shows the carbon pools considered in the FREL/FRL.

Table 5: Carbon pools accounted for in the FREL/FRL

Due to these concerns, such removals are not accounted under the current FREL/FRL.

<sup>&</sup>lt;sup>6</sup> However, two issues need to be further considered:

<sup>1.</sup> As the forests in Lao PDR are considered to be under constant use/disturbance by the local communities, it is difficult to judge whether any default or global data can be reasonably applied; and

<sup>2.</sup> It is not clear whether such removals can be argued as 'anthropogenic', since among the "Current Forest" (currently 58% of the total land area), currently:

<sup>• 16%</sup> is Production Forest area, where currently very limited forest enhancement activities taking place except for in tree plantations (<1% of the total land area);

<sup>• 35%</sup> is Protection Forest area, and 26% is Conservation Forest area which according to legislation should be managed for limited human activities, and currently have limited forest enhancement activities; and

<sup>• 23%</sup> is under "Un-categorized" status, which are typically under village management. These areas are often degraded forests, or due to lack of clear ownership and management system, and proximity to village residential areas, they are seen as at risk of forest disturbances.

Carbon Pools	Selected?	Justification / Explanation	
Above Ground Biomass (AGB)	Yes	AGB consists the majority of the forest biomass in Lao PDR, thus, considered as a significant carbon pool.	
Below Ground Biomass (BGB)	Yes	On average, BGB constitutes 37.6% of the AGB per ha. Thus, BGB is considered as a significant carbon pool.  Due to the lack of country-specific data, the IPCC default values were used for the estimation.	
Dead Wood (DW)	No	The 2 <sup>nd</sup> NFI involved measurement of DW. The results showed that emissions from DW through deforestation account only 2.3% of the sum of the AGB, BGB and DW, therefore, considered insignificant (See "Annex 2: Emission/Removal Factors Report" for more details).  Lao PDR currently lacks complete data to account DW in the FREL/FRL, and considers to improve this in the measurement of the next NFI.  Exclusion of DW is considered to be conservative on the basis of future improvements in forest management being successful.	
Litter	No	As carbon stock of litter was assumed to be small under moist tropical climate such as in Lao PDR (2.1 tC/ha for Lao PDR according to the IPCC 2006 Guideline Volume 4, Chapter 2, Table 2.2), the discussions leading up to the 2nd NFI determined not to measure litter in the 2nd NFI. The emissions from litter can be assumed to be smaller than that of the DW explained above. Inclusion of litter in the measurement will be considered in the future step-wise improvement.  Exclusion of litter is considered to be conservative on the basis of future improvements in forest management being successful.	
Soil	No	There is no reliable country specific data for soil organic carbon. Inclusion of soil organic carbon in the measurement will be considered in the future step-wise improvement.  Exclusion of soil organic carbon is considered to be conservative on the basis of future improvements in forest management being successful.	

#### 3.3. Gases

The following table shows the GHG considered in the FREL/FRL.

Table 6: Gases accounted for in the FREL/FRL

Greenhouse gases	Selected?	Justification / Explanation
CO <sub>2</sub>	Yes	The FREL/FRL account for CO₂ emissions and removals.
Non-CO2 (CH4 and N2O)	No	Shifting cultivation is an important disturbance event nationally, where nearly 170,000ha/year of forest lands are assumed to be affected by slash and burn practices. CH4 and N2O are the gases emitted from biomass burning.  The estimates of emissions from non-CO2 gases caused by shifting cultivation account for 2.9% of all forest-related CO2 emissions in the reference period (2005-2015) <sup>7</sup> .

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<sup>&</sup>lt;sup>7</sup> The estimation followed the method described in IPCC 2006, Volume 4, Chapter 2, Section 2.4 (Equation 2.27). The assumption was that non-CO2 gases caused by shifting cultivation originates from forest land (i.e. 'Current Forest' + 'Potential Forest') converted to Upland Crop (UC). As the forest maps are developed with 5-year intervals, the estimation assumed: i) areas of UC as the areas burnt on the year satellite imagery was obtained; ii) extracted the changes from each forest class to UC in 2005-2010 and 2010-2015, and iii) calculated an average as the annual

However, by the nature of shifting cultivation which is defined as not being permanent, the area of shifting cultivation can only be finally determined through a retrospective confirmation of plots not continuing to be cultivated, which would take place during the next mapping cycle. Therefore, it is difficult to confidently estimate emissions of non-CO2 gases from shifting cultivation for the current period (See "Annex 1: Activity Data Report" for more details).

There is no country-specific biomass combustion factor which can be applied for slash and burn activities.

Forest fires, which are mostly uncontrolled spreading of fire from slash and burn activities, are another source of emissions of CH4 and N2O. Lao PDR currently does not have a national system to accurately monitor forest fires and its affected areas, and it is also a challenge to distinguish whether the fires are anthropogenic or naturally caused.

For the above reasons, non-CO2 gases (CH4 and N2O) are excluded from the FREL/FRL. Exclusion of CH4 and N2O is considered to be conservative.

However, Lao PDR considers accounting of non-CO2 gases (CH4 and N2O) as one area for technical improvement into the future.

#### 3.4. Scale

The scale of Lao PDR's FREL/FRL is national.

Lao PDR developed the Forest Type Maps for years 2000, 2005, 2010 and 2015, of which the Forest Type Maps for 2005, 2010 and 2015 are used for deriving the Activity Data (AD) for the current FREL/FRL. Lao PDR also conducted the 2<sup>nd</sup> National Forest Inventory (NFI) during 2015-2017, which provides biomass stock data for the forest classes measured, and used for estimating the Emissions/Removal Factors. These two national level data are considered sufficient to develop the FREL/FRL for the national scale.

#### 3.5. Reference period

The reference period of the FREL/FRL is 10 years, with 2005/01/01 as the start-date and 2014/12/31 as the end-date<sup>8</sup>.

burnt area for the reference period. The 'Mass of available fuels' for each forest class was calculated from the 2nd NFI data and other available data sources (e.g. IPCC). The combustion factors were taken from the IPCC Guideline 2006, V4 02 Ch2 Generic table 2.6.

<sup>8</sup>In fact, as explained in Section 4.2.1, the FTM 2005 used the satellite imagery taken in 2004-2005 dry season, and the FTM 2015 used that of 2014-2015 dry season which compose the 10-year period of the FREL/FRL. Forest Type Maps (FTMs) produced using satellite imagery of year (X) to year (X+1) dry season is considered as the FTM of the start date of year (X+1). This means:

- FTM 2005 will be regarded as a map of 2005/01/01 (the map was developed from the satellite imagery collected during 2004 to 2006, in order to create a most suitable cloud-free mosaic. By taking the middle year, i.e. 2005, the map is considered as the state of land/forest cover as of 2005/01/01.),
- FTM 2010 is considered as a map of 2011/01/01,
- FTM 2015 is considered as a map of 2015/01/01.

As most of the land cover changes occur during the dry season (Oct – Apr.), when natural conditions are more amenable for human intervention, this application is considered reasonable. The same rule will be applied to the future MRV which is currently planned to use 2018 - 2019 dry season imagery.

The reason for the selection of 2015 as the end-date is because the latest available Forest Type Map used for the development of the AD is for the year 2015, and there is no alternative data available. On the other hand, the reason for the selection of 2005 as the start-date is due to the availability of reliable dataset which covers the entire national territory. Some background in arriving at this decision is presented below:

- 1) Forest Type Maps have been developed at a frequency of 5 years for a number of reasons: a) based on considerations in the early stages of REDD+ readiness, the Government initiated the development of Forest Type Maps in 2010; b) Government's intention is to carry out NFIs every 5 years, and a corresponding interval for Forest Type Maps was considered appropriate to cross-reference; c) as large part of Lao PDR's landscape is shifting cultivation, a 5-year interval was deemed as the maximum interval to capture resulting land/forest use changes. As a result, Forest Type Maps for years 2000, 2005, 2010 and 2015 are the official national-level maps only available as for now.
- 2) By using the Forest Type Map 2010 as the benchmark map, the Forest type Map 2000, 2005 and 2015 were developed through change detection method. As shown in the table below, there is a concern on the adequacy of using the Forest Type Map 2000 due to the significant difference in the resolution of satellite imagery used. There is a relatively high possibility of uncertainty due to the accumulated errors originating from change detection (overlaying 2010 2005 imagery to develop the Forest Type Map 2005, and then 2005-2000 imagery to develop the Forest Type Map 2000).
- 3) As the FREL/FRL for the FCFP-CF Emissions Reduction Program intends to select 2005-2015 for its reference period, selecting the same reference period for the national FREL/FRL will help to maintain consistency between the two.

Table 7: Resolution of the satellite imagery used for the Forest Type Map development

		7 4004 101 4110 101000 176	- map acrosopinom
Year	2000	2005	2010 and 2015
Satellite Image	Landsat 5	SPOT4/5 MS	RapidEye
Resolution	30m	10m	5m

### 4. CONSTRUCTION OF THE FREL/FRL

#### 4.1. Background context and method of construction

#### 4.1.1. National circumstances and adjustments

According to Decision 12/CP.17 II. Paragraph 9, countries can submit information and rationale on the development of FREL/FRLs, including details of national circumstances and if adjusted include details on how the national circumstances were considered.

For the construction of FREL/FRLs, Lao PDR conducted a thorough analysis of its national circumstances, including the country context and drivers of forest cover change. This was particularly done as a part of the development of National REDD+ Strategy (NRS) (in its final stage draft at the time of this modified FREL/FRL submission).

#### a. Country context

Lao PDR is a mountainous country, known in the past for its rich forests and biodiversity. In recent decades, however, deforestation and forest degradation have been rampant. Much of Lao PDR's population live in close proximity to, and have historically depended on, natural forests for their livelihoods. Moreover, as hydropower generation and export is a significant source of national income, sustainable management of its watersheds is a vital national agenda.

The importance of forest resources and its sustainable management are enshrined in the Government's highest level policies, including the 8th National Socio-Economic Development Plan (8th NSEDP 2016-2020), the Green Growth Strategy (under drafting), the Central Party's Resolution on Land (2017), the Forestry Strategy 2020, as well as in Lao PDR's Nationally Determined Contributions (NDC). As mentioned above, the NRS provides a strategic direction for Lao PDR to roll-out REDD+ nationwide.

Lao PDR has engaged in REDD+ since 2007, when Lao PDR joined the Forest Carbon Partnership Facility (FCPF). A National REDD+ Task Force (NRTF) was created and worked with support from technical advisers and several development partners. The REL/MRV Technical Working Group was established under the NRTF, and is leading technical discussions related to FREL/FRL development, MRV and the overall national forest monitoring system. The REL Drafting Team which consists of technical staff from FIPD is taking the main role on constructing the FREL/FRL with support from development partners, namely JICA.

#### b. <u>Drivers of forest cover change</u>

The draft NRS identifies five main drivers of forest cover change and intervention programs as below.

Table 8: National-level drivers and intervention programs

Drivers	Intervention Programs
1. Expansion of agriculture land into the	1. Development of sustainable agriculture in
forests.	coordination with forest protection.
2. Conversion of forest land for infrastructure development and mining (including resettlement, mining, hydro-power, urban expansion).	2. Infrastructure (including resettlement and urban expansion) and mining development in coordination with forest protection.
3. Forest degradation from unsustainable	3. Sustainable timber harvesting (wood and
timber harvesting and NTFP collection.	forest products) and forest management

4. Shifting cultivation and forest fires.	4. Turning pioneering shifting cultivation to sedentary cultivation, controlling forest fires and forest restoration (carbon stock enhancement).
5. Conversion of natural forest to commercial	5. Development of sustainable commercial
tree plantation areas.	tree plantation.

Source: Draft NRS, version Feb. 2018

#### c. Adjustments

Lao PDR does not wish to adjust its FREL/FRL.

#### d. Validity period of the proposed FREL/FRL

The draft NRS is developed mostly based on the analysis of land/forest cover change as well as the experiences of Lao PDR's forestry sector during 2005-2015, and sets out strategic actions towards 2025 and vision to 2030. In this context, Lao PDR considers the proposed FREL/FRL as valid for the period with that of the NRS (i.e. 2015-2025). However, with the future MRV and other information, Lao PDR may modify the validity period as appropriate.

#### 4.1.2. General methodologies

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.

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, as explained in Section 3.1, 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:

 $\Delta C_B$  = annual change in carbon stocks in biomass on land converted to other land-use

category, in tonnes C yr-1

 $\Delta C_G$  = 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

 $\Delta C_L$  = 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 ( $\Delta C_G$ ) and carbon losses ( $\Delta C_L$ ) 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

$$\Delta C_{CONVERSION} = \sum_{i} \left\{ (B_{AFTER_{i}} - B_{BEFORE_{i}}) \bullet \Delta A_{TO\_OTHERS_{i}} \right\} \bullet CF$$

(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 2010-2015. 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 2<sup>nd</sup> National Forest Inventory combined with country-specific allometric equations, and an independent biomass measurement data for RV class<sup>9</sup>. IPCC default and data from neighbouring 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 4.2.3). The approach uses the tree stump records measured through the 2<sup>nd</sup> NFI to complement the impact of selective logging which was considered as underrepresented. The approach also complements quantifying forest degradation in stable forest classes where forest biomass data is limited.

e reason for not using the 1<sup>st</sup> NFI data is explained in the Annex 10: Emissi

<sup>&</sup>lt;sup>9</sup> The reason for not using the 1<sup>st</sup> NFI data is explained in the Annex 10: Emission and Removal Factors Report.

#### 4.2. Historical data used for the construction of the FREL/FRL

#### 4.2.1. Activity Data<sup>10</sup>

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<sup>11</sup>; 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 emission from forest degradation by selective logging is estimated by proxy-based approach, therefore, explained separately in Section 4.2.3.

#### Development of the Forest Type Maps 2005, 2010 and 2015

In Lao PDR, the Forest Type Maps were developed for the national level for years 2005, 2010 and  $2015^{\,12}$ . Importantly, Forest Type Maps are developed applying the 'Level 2' of land/forest classification system, and then further stratified into the five land/forest strata. The satellite imagery used for creating Forest Type Map 2005, 2010 and 2015 are summarized in Table 9 below. The mapping scale was decided to be 1/100,000, and the minimum mapping unit of 0.5ha was consistently used for developing the Forest Type Maps.

Table 9: Details of the satellite imagery used for the development of Forest Type Maps

Name	SPOT4 / 5 MS	RapidEye	RapidEye
Year	2005	2010	2015
Observation	From Oct. 2004 to Apr.	From Nov. 2010 to Mar.	From Nov. 2014 to Feb.
term	2006	2011 for Forest Type Map	2015 for Forest Type Map
		2010	2015
Number of	114	146	94
scenes			

<sup>&</sup>lt;sup>10</sup> The detailed process of the development of AD is described in "Annex 1: Activity Data Report" attached to the submission.

Corresponding to the dates of these satellite images, the actual change analysis is for the 6-year period of 2005-2011 and the 4-year period of 2011-2015. For the remainder of this submission and other official documentation, the maps and change analysis periods reference the official names based on uniform 5-year periods, but, needs to be understood that the actual analysis applied is not uniformly for each five years.

<sup>&</sup>lt;sup>11</sup> The maps are officially referred to as the "maps of 2005, 2010, and 2015"; and the change analysis are correspondingly referred to as covering for the periods of "2005-2010 and 2010-2015". However, it is noted that these maps were actually produced with satellite imageries from the dates of:

<sup>• &</sup>quot;2005 map": Oct. 2004 - Apr. 2006;

<sup>• &</sup>quot;2010 map": Nov. 2010 - Mar. 2011;

<sup>• &</sup>quot;2015 map": Nov. 2014 - Feb. 2015.

<sup>&</sup>lt;sup>12</sup> As Lao PDR selected 2005-2015 as the reference period, the FTM 2000 is not used for the FREL/FRL, thus not explained here.

Resolution	10m	5m	5m
Bands	Band1: Green	Band1: Blue	Band1: Blue
	Band2: Red	Band2: Green	Band2: Green
	Band3: NIR	Band3: Red	Band3: Red
	Band4: SWIR	Band4: Rededge	Band4: Rededge
		Band5: NIR	Band5: NIR

The general process for the development of Forest Type Map 2005, 2010 and 2015 is described in Figure 2. In order to secure time-series consistency among the maps of different years, and also taking into account costs and map quality, first, Forest Type Map 2010 was developed as the benchmark map. Next, the satellite imagery of year 2010 was compared with the satellite imagery of years 2005 and 2015 respectively to extract the changes over the two respective periods (i.e. change detection). Then, the changed areas were overlaid with the Forest Type Map 2010 to develop Foerst Type Map 2005 and 2015.

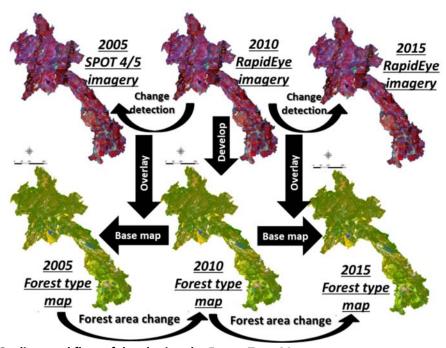


Figure 2: Outline workflow of developing the Forest Type Maps

From the draft Forest Type Maps developed, initial Forest Change Maps for the period of 2005-2010 and 2010-2015 were generated to conduct initial analysis of forest change and identify illogical changes. Through this diagnostic check, all of these areas were double-checked and corrected.

Then, the initial Forest Type Maps with Level 2 classification were stratified into five strata (as explained in Section 2.2) as the areas for each year shown in Table 10.

Table 10: Area by five land/forest strata

Unit: ha, percentage

	2015	%	2010	%	2005	%
Stratum 1	2,605,557	11.3%	2,613,226	11.3%	2,618,169	11.4%

Stratum 2	9,437,688	40.9%	9,721,635	42.2%	9,961,368	43.2%
Stratum 3	1,188,198	5.2%	1,215,712	5.3%	1,272,006	5.5%
Stratum 4	6,300,445	27.3%	6,042,075	26.2%	6,183,370	26.8%
Stratum 5	3,522,370	15.3%	3,461,610	15.0%	3,019,344	13.1%
Total	23,054,258	100%	23,054,258	100%	23,054,258	100%

#### **Design-based area estimation of Activity Data**

Using the stratified Forest Type Maps, Lao PDR decided to apply design-based area estimation with respect to generating statistically reliable estimates of AD. This method follows good practice recommended by Olofsson et al. (2014), which regards the stratified Forest Type Maps to serve as an initial stratification of the population of interest for the purposes of designing and collecting reference data which will actually be used to estimate the actual changed areas<sup>13</sup>.

The final AD based on the stratification for the period 2005-2010 and 2010-2015 are shown in Table 11 and Table 12 below.

Table 11: Activity data 2005 - 2010

Unit: ha 2010 Stratum 1 Stratum 2 Stratum 3 Stratum 4 Stratum 5 2005 Stratum 1 2,502,263 3,066 0 1,806 2,449 Deforestation 9,229,338 0 Stratum 2 3,685 363,636 92,783 Degradation Stratum 3 0 151 1,163,630 39,045 29,008 Restoration Stratum 4 217 401,260 4,109 5,291,029 Reforestation 492,130 0 0 3,067,614 Stratum 5 0 367,038 No Change

Table 12: Activity data 2010 - 2015

2010 Stratum 1 Stratum 2 Stratum 4 Stratum 5 Stratum 3 2,530,772 482 17 1,186 8,215 2005 Stratum 1 0 9,062,250 425 380,043 142,609 Stratum 2 0 42 1,153,689 21,440 15,516 Stratum 3 430,826 0 367 5,579,623 243,032 Stratum 4 391,406 3,092,318 0 0 0 Stratum 5

Deforestation
Degradation
Restoration
Reforestation
No Change

Unit: ha

<sup>&</sup>lt;sup>13</sup> The detailed process is described in "Annex 1: Activity Data Report" attached to the submission

#### 4.2.2. Emission and Removal Factors<sup>14</sup>

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. The source of data are as follows;

#### Five forest classes subject to the 2<sup>nd</sup> NFI (EG, MD, DD, CF and MCB)

For strata 1 (EG), 2 (MD, CF, MCV) and 3 (DD), measurement data from the 2nd NFI is used.

The 2nd NFI was conducted in the dry seasons of 2015-2016 and 2016-2017, and a total of 559 survey plots were distributed across these strata through systematic-random-sampling.

Country-specific allometric equations were developed and applied for the three major Level 2 forest classes (EG, MD and DD). For the other two forest classes (CF and MCB) the allometric equations developed in Vietnam were used.

The BGB is estimated using the root-shoot ratio derived from the IPCC Guideline 2006 Volume 4 Chapter 4 Table 4.4. (0.2 for AGB < 125, and 0.24 for AGB > 125).

Biomass is converted to carbon stock by using the carbon fraction (CF= 0.46 or 0.47 depending on the land/forest class) derived from the IPCC Guideline 2006, Volume 4, Chapter 4, Table 4.3.

#### Regenerating Vegetation (RV)

Carbon stock of RV is estimated based on the results from the "RV survey"<sup>15</sup>. As RV occurs most prominently in northern Laos, survey sites were distributed in three provinces in the northern region, one province in the central region and one province in the southern region. A total of 120 survey plots (40 survey clusters with three survey plots each) were distributed and the measurement of DBH for trees, and measurement of the biomass weight for the understories were conducted.

#### Bamboo (B)

The E/R factors of the Northern Central Coast region of Vietnam is used.

#### Plantations (P)

Carbon stocks were derived from default factors of the IPCC database.

#### Other land/forest classes

The carbon stocks of remaining land/forest classes are derived mostly from IPCC Guideline 2006.

As the FREL/FRL is 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:

<sup>&</sup>lt;sup>14</sup> The detailed process of the development of E/R factors is described in "Annex 2: Emission/Removal Factors" attached to the submission.

<sup>&</sup>lt;sup>15</sup> DOF, et al. (2017). Development of a Lao-specific Equation for the Estimation of Biomass of 'Regenerating Vegetation' and Determination of the Threshold Years for its Regeneration into Forest. <a href="http://dof.maf.gov.la/en/home/">http://dof.maf.gov.la/en/home/</a>

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

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.

The following table shows the resulting carbon stock of the five strata.

Table 13: Carbon stock of the five strata

Strata	tC/ha
Stratum 1 (EG)	200.0
Stratum 2 (MD, CF, MCB)	88.1
Stratum 3 (DD)	43.2
Stratum 4 (P, B, RV)	17.9
Stratum 5 (NF)	4.9

By taking the difference in average carbon stock of each land/forest strata the E/R factors are derived as shown in the table below.

Table 14: Emissions/Removals Factors for changes (tCO2e)

able 1 ii 1 iiii balana i adaa i a a a a a a a a a a a a a a a						
	Stratum 1 (EG)	Stratum 2 (MD, CF, MCB)	Stratum 3 (DD)	Stratum 4 (P, B, RV)	Stratum 5 (NF)	
Stratum 1 (EG)		-410.5	-575.1	-667.6	-715.4	
Stratum 2 (MD, CF, MCB)	410.5		-164.6	-257.1	-304.9	
Stratum 3 (DD)	575.1	164.6		-92.6	-140.3	
Stratum 4 (P, B, RV)	667.6	257.1	92.6		-47.8	
Stratum 5 (NF)	715.4	304.9	140.3	47.8		

#### 4.2.3. Supplementary analysis of the impact of selective logging

Unsustainable selective logging, both legal and illegal, is considered as a major driver of forest degradation. Emissions from such selective logging in addition to degradation accounted for through the Forest Cover Change Matrix (Section 4.2.1), predominately associated with rotational agriculture, could make forest degradation a significant source of emission for Lao PDR. Moreover, considering the Government's strong commitment to tackle illegal logging, the FREL/FRL attempts to explore methods to quantify historical emissions caused by selective logging.

The remote sensing technology currently applied in Lao PDR's forestry sector does not allow reasonable assessment of the historical biomass loss caused by selective logging. Other information sources, such as the government statistics related to logging, UN-COMTRADE statistics on timber export and published literature were reviewed, however they were found to be insufficient to provide reasonable estimates.

On the other hand, the 2<sup>nd</sup> NFI recorded the diameter and height of tree stumps observed in the measurement plots. By using this data the FREL/FRL attempts to estimate the historical emissions caused by selective logging through the following steps:

In the 2<sup>nd</sup> 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
- 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<sup>16</sup>:

```
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 2<sup>nd</sup> 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)
- 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.

<sup>&</sup>lt;sup>16</sup> 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.

An equation which allows the estimation of years required for wood materials to decompose from the experimental study in Pasoh in the Malaysian Peninsula<sup>17</sup> was referenced. Figure 3 below shows the change of relative value of material weight under different temperatures (Table 15) and climate conditions (e.g. precipitation) which is considered to be reasonably similar to that of Lao PDR.

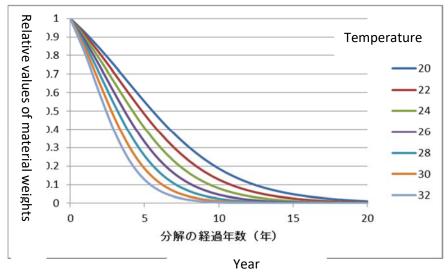


Figure 3: Relative values of material weights over years

Table 15: 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 16, 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 2<sup>nd</sup> NFI were felled within 12 years before its field survey (implemented in dry season of 2015-2016 and 2016-2017).

Table 16: Temperature and precipitation in Lao PDR (2014) 18 and Pasoh (study site)

	Temperature	Precipitation
	°C	mm/Y
Luang Prabang	26.6	1469
Vientiane capital	27.0	1349

<sup>&</sup>lt;sup>17</sup> 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

21

<sup>&</sup>lt;sup>18</sup> Lao Statistics Bureau (http://www.lsb.gov.la/en/Meteorology14.php)

Savannakhet	26.5	1461
Champasack	27.3	2416
Average	26.9	1674
Pasoh*	25.5	1724.4

<sup>\*</sup>Recorded in the forest

#### 4.3. Calculation of the FREL/FRL

#### 4.3.1. Emission and removals calculated based on changes among land/forest strata

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 2005-2015 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)<sup>19</sup>.

Table 17: Typologies of change for removals

Sinks	From	То	Adjustment of removals
Restoration	Stratum 4 (RV)	Stratum 1, 2 and 3	In principle, 40-years <sup>20</sup> 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 with higher biomass	In principle, 20 years <sup>21</sup> is assumed as the transition period for forest with lower biomass to reach forest with higher biomass.

<sup>&</sup>lt;sup>19</sup> 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.

<sup>&</sup>lt;sup>20</sup> The assumption is based on references in <u>the FCPF Carbon Fund Emissions Reduction Program Document of neighboring Vietnam</u>, 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).

<sup>&</sup>lt;sup>21</sup> 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.

	Stratum 3 (DD)		
Reforestation	Stratum 5 (non-forest)	Stratum 4 (predominant ly, 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) <sup>22</sup> .  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 (2005-2015) 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), 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 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) as shown in Table 18 below. The respective estimated areas were multiplied with the accumulated biomass of the respective stratum calculated based on typologies in Table 17 above, and the results were deducted as over-estimated removals. The resulting over-estimation from such removals, which was 212,539 tCO<sub>2</sub>e, were deducted from "Restoration" of 2010-2015 period.

Table 18: Over-estimated removals tracked

	Stratum in 2005	Stratum in 2010	Stratum in 2015	Estimated area (ha)*	Emissions to be deducted from Reversals (tCO₂e)
Change	4	2	3	2	73
patterns from time series	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

<sup>\*</sup>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 (See footnote 13 in Section 4.2.1)

#### 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

<sup>&</sup>lt;sup>22</sup> The actual mapping cycle of 6 years and 4 years are also reflected in the actual calculation.

the actual accumulated biomass which may be lower. For example, a MD forest which is in its early regrowth stage (e.g.  $10^{th}$  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 19 below. The respective estimated areas were multiplied with the accumulated biomass of each land calculated based on typologies in Table 17 above. The resulting over-estimation of emissions from deforestation, which was  $788,306 \text{ tCO}_2\text{e}$ , and over-estimation of emissions from forest degradation, which was  $502,065 \text{ tCO}_2\text{e}$ , were estimated and deducted, respectively.

Table 19: Tracked over-estimation of emissions

	Stratum in 2005	Stratum in 2010	Stratum in 2015	Estimated area (ha)	Overestimation of emissions to be deducted (tCO <sub>2</sub> e)	
Change	4	1	5	1	765	
patterns from time series	4	2	3	2	220	
time series	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					
					(Deg.: 502,065)	

<sup>\*</sup>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)

The comparison of before and after the adjustment is shown in the following table.

Table 20: Comparison of before and after adjustment

	Ве	fore adjustm	ent	After adjustment			
	2005-2010 (tCO₂e)	2010-2015 (tCO <sub>2</sub> e)	Annual average 2005-2015 (tCO <sub>2</sub> e/yr)	2005-2010 (tCO <sub>2</sub> e)	2010-2015 (tCO <sub>2</sub> e)	Annual average 2005-2015 (tCO₂e/yr)	
Deforestation	57,616,664	63,140,029	12,075,669	57,616,664	62,351,723	11,996,839	
Degradation	99,570,637	100,764,909	20,033,555	99,570,637	100,262,844	19,983,348	
Reforestation	-17,532,039	-18,696,023	-3,622,806	-17,532,039	-14,956,818	-3,248,886	
Restoration	-105,228,824	-110,808,188	-21,603,701	-18,236,927	-24,609,792	-4,284,672	

The average annual historical emissions and removals over the reference period after the adjustment of removals are described in the following table.

Table 21: Historical Emissions and Removals – based on changes among land/forest strata

	Emissions(+)/ Removals(-)						
Source/Sink	2005-2010 (tCO2e)	2010-2015 (tCO2e)	Annual average for 2005-2010 (tCO2e/year)				
Deforestation	57,616,664	62,351,723	11,996,839				
Forest Degradation	99,570,637	100,262,844	19,983,348				
Reforestation	-17,532,039	-14,956,818	-3,248,886				
Restoration	-18,236,927	-24,609,792	-4,284,672				
Total Emissions	157,187,301	162,614,567	31,980,187				
Total Removals	-35,768,966	-39,566,610	-7,533,558				

#### 4.3.2. Emissions from selective logging (degradation)

As explained in Section 4.2.3, the 2<sup>nd</sup> 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, to estimate the assumed emissions from such logging events as shown in Table 22 below.

Table 22: Estimated total emissions from selective logging

	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) (	9,186,797			

#### 4.3.3. Results of calculation

The FREL/FRL for Lao PDR is an aggregation of the historical emissions and removals calculated based on land/forest strata as explained in Section 4.3.1, and the emissions from selective logging as explained in Section 4.3.2.

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

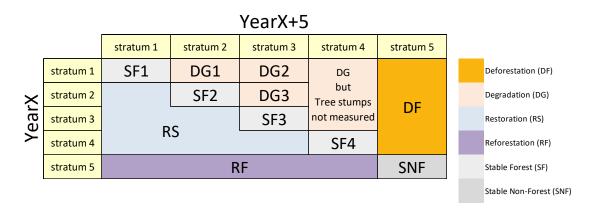


Figure 4: Annotated change matrix among land/forest strata for addressing double-counting in degradation

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). 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 2<sup>nd</sup> 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<sup>23</sup>, 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.
- 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

As the result, the emissions and removals for the period 2005-2010 and 2010-2015 per sources and sinks, and its total over the entire reference period (2005-2015) is as summarized in Table 23 below.

<sup>&</sup>lt;sup>23</sup> The timing of the felling of the tree stump cannot be accurately determined, making the association with the Forest Cover Change Matrix a challenge.

Table 23: Average Annual Historical Emissions and Removals over the Reference period

	Emissions(+)/ Removals(-)						
Source/Sink	2005-2010 (tCO2e)	2010-2015 (tCO2e)	Annual average for 2005-2015 (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 24 below.

Table 24: Annual historical emissions and removals by sources and sinks

	Annual historica							
Year	Emissions: Deforestation	Emissions: Forest Degradation	Removals: Reforestation	Removals: Restoration	Reference level (tCO2e/yr) 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 -7,533,5							

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 25.

Table 25: Proposed reference emissions and removals for Lao PDR (2005-2015)

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

#### 5. ASSESSMENT OF UNCERTAINTY

#### 5.1. Identification and assessment of sources of uncertainty

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.

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.

#### 5.2. Assessment of uncertainty of Activity Data (AD) 24

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.

Lao PDR acknowledges the lack of an established Standard Operating Procedure (SOP) for forest mapping, and plans to develop such SOP through the 1<sup>st</sup> MRV in 2019. This shall contribute to reduce the level of uncertainty related to AD.

Errors are calculated following the good practices for assessing accuracy assessment of land change as recommended in Olofsson et al (2014)<sup>25</sup>. To employ this approach, the land use change classes were validated using Collect Earth<sup>26</sup>. The results are shown in the tables below:

Table 26: 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%					

Table 27: Map accuracy and uncertainty of Activity Data 2010 – 2015

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<sup>&</sup>lt;sup>24</sup> See Annex 1: Activity Data Report for details.

<sup>&</sup>lt;sup>25</sup> Olofsson et. al., 2014.

<sup>&</sup>lt;sup>26</sup> Details at: http://www.openforis.org/tools/collect-earth.html

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%		•		•	

#### 5.3. Assessment of uncertainty of Emission/Removal factors<sup>27</sup>

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 28 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 (2<sup>nd</sup> 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 2<sup>nd</sup> 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 5 REDD+ Strata by using weighted value based on area proportion;
- c. Calculate the uncertainties of E/R factors (Table 28); and
- d. Calculate the uncertainty of E/R factors per sources and sinks (Table 29).

Table 28: Emission/Removal Factors Uncertainty

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<sup>&</sup>lt;sup>27</sup> See Annex 2: Emission/Removal Factors Report for details.

	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 29 Uncertainty of E/R factors per sources and sinks

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

#### 5.4. Quantification of uncertainty in FREL/FRL setting

#### 5.4.1. Uncertainty of the emissions and removals based on changes among 5 REDD+ strata

Based on the uncertainty assessment of AD and E/R factors, the uncertainty of the emissions and removals through changes among the 5 REDD+ strata is calculated per sources and sinks using propagation of error approach. Table 30 and Table 31 show the results of the calculation, which are 19.6% for emissions and 19.3% for removals.

Table 30: Uncertainty of the emission level for 2005-2010 and 2010-2015 by sources/sinks –based on changes among 5 REDD+ strata

on changes a	mong 5 KLDD	· Strutu				
		2005-2010			2010-2015	
Source/Sink	Amount (tCO <sub>2</sub> e)	Uncertainty range (tCO₂e)	Uncertainty range (%)	Amount (tCO <sub>2</sub> e)	Uncertainty range (tCO <sub>2</sub> e)	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 31: Uncertainty of the reference level over the reference period – based on changes among 5 REDD+ strata

	Per Source	es and sinks (20	05-2015)	Per Emission/removal (2005-2015)		
Source/Sink	Amount (tCO₂e/year)	Uncertainty range (tCO₂e/year)	Uncertainty range (%)	Amount (tCO <sub>2</sub> e/year)	Uncertainty range (tCO <sub>2</sub> e/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%	31,620,320	0,232,366	19.0%
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%	-1,333,336	-1,437,714	19.370

#### 5.4.2. Uncertainty of emissions by selective logging

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 4.2.3, uncertainty of Forest Type Map 2015 shown in Table 32 and uncertainty of E/R factors shown in Table 33 are used as the two parameters.

Table 32: Uncertainty of the Foerst 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%
МСВ	107,880	35.9%
DD	1,188,198	12.7%

Table 33: Uncertainty of the E/R factors for the uncertainty assessment of emissions from

selective logging

	Uncertainty		AGB+BGB	Uncertainty			
Forest class	1	2	3	4	(5)	Ave tCO2/ha	(%)
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%
МСВ	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 (2<sup>nd</sup> 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 2<sup>nd</sup> NFI): expert judgement for uncertainty of the E/R factors (3.1-8.7%)

The resulting uncertainty is estimated as 21.7% as show in the table below<sup>28</sup>.

Table 34: Estimated emissions for degradation from selective logging

	Emissions (tCO2e)	Uncertainty (%)
EG	46,353,989	37.10%
MDF	44,531,308	34.40%
CF	336,245	57.10%
МСВ	2,024,360	54.00%
DD	16,995,658	37.10%
Total	110,241,559	21.70%

#### 5.4.3. Estimation of overall uncertainty

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

Table 35: Overall uncertainty of the proposed FREL/FRL

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

<sup>&</sup>lt;sup>28</sup> 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.

## 6. TRANSPARENCY AND DATA NECESSARY FOR THE RECONSTRUCTION OF FREL/FRL

Lao PDR is in the process of developing its National Forest Monitoring System (NFMS) including the database system and web-based portal.

For the development of a database system which enables automated estimation of forest carbon stocks and its changes over time, this will be done through developing functions to:

- 1. Archive, calculate and output the AD
- 2. Archive, calculate and output the E/R factors
- 3. Calculate, evaluate and output the forest carbon stocks and its changes, and convert to tCO2e.

The advantage of such system is that it will unify all the existing official data used for the emissions and removals into one single database, reduce costs by means of automating, avoid the risks of human errors in the entire estimation process, and ensure transparency of the estimation methods and results. Moreover, overlaying such information with the administrative boundary data, forest category data, and other forestry-related data will allow the data users to analyse forests according to their interest.

Table 36: Data to be presented in the NFMS web-portal

Data related to AD	Data type
Forest Type Map 2000, 2005, 2010, 2015	Raster data
Forest cover change map 2000-2005, 2005-2010, 2010-2015	Raster data
	(partly vector data)
Satellite imagery used for the development of Forest Type Maps	Raster data
Landsat (2000), SPOT4, 5 MS(2005), RapidEye (2010, 2015)	
(both false colour and true colour)	
Data related to E/R factors	Data type
1 <sup>st</sup> NFI data	Tabular data
2 <sup>nd</sup> NFI data	Tabular data
Other data	Data type
Administrative area: national, province, district	Vector data
Forest category: Production Forest, Protection Forest,	Vector data
Conservation Forest	
Reports	Data storage
FREL/FRL Report to the UNFCCC including annexes	To be made available in
	UNFCCC website
1st National Communication to the UNFCCC	Available in UNFCCC website
2 <sup>nd</sup> National Communication to the UNFCCC	

The NFMS web-portal will enable access through internet<sup>29</sup>. The information to be presented in the NFMS web-portal will be further enhanced, although step-wise, to ensure transparency.

<sup>&</sup>lt;sup>29</sup> <http://nfms.maf.gov.la:4242/nfms/>

#### 7. ISSUES FOR FUTURE FREL/FRL AND MRV

#### 7.1. Issues for future improvement

Lao PDR has identified the areas for future improvement on its FREL/FRL and MRV as follows:

#### 1) Areas for future improvements related to the Activity Data

#### Improvement of classification between RV and MD

Under Forest Type Maps with the Level 2 classification, distinguishing RV and MD is a challenge, especially when the land is under continuous phases of regeneration. The remote sensing team tried using ancillary data, such as the threshold year for RV to regenerate into MD. For the future forest mapping, Lao PDR will attempt to explore methods to fine-tune the classification in order to enable further analysis of land/forest cover change over time.

#### Updating Forest Type Map 2015 map and Forest Type Maps

Distinguishing UC and OA is also a challenge, as they have very similar texture on satellite imagery. Therefore, in the current mapping method, continuous interpretation of a land as UC over the two time periods was determined as permanent agricultural land and the classification of the latter year was revised to OA class. In the future, Lao PDR may explore using options, such as the technologies to analyze 'big data', multi-temporal satellite dataset available, and GIS data from different sources (e.g. land concession data), which meet its needs.

#### Further capacity building of the remote sensing, GIS and IT engineers

Under rapid innovation of remote sensing, GIS and IT technologies, demand for sufficient number of competent engineers/team is increasing. The skills and knowledge of the skilled senior engineers need to systematically be passed on to the younger generation, and there is also an emerging need for IT engineers who can manage and operate database systems which handle a large and diverse range of digital data. As one measure, a Standard Operation Procedure (SOP) for forest mapping is planned to be developed through the 1st MRV currently scheduled in 2019.

#### 2) Areas for future improvements related to the Emission/Removal Factors

#### Carbon stock of RV

The carbon stock of RV was measured separately from the 2<sup>nd</sup> NFI and calculated from the average carbon stock of different years, therefore, there is a limitation in the representativeness of data which resulted in relatively high uncertainty. The measurement did not include DW. The future NFI could incorporate the measurement of carbon stock of RV, including DW, in its design.

#### Continuous improvement of E/R factors

Default values from the IPCC Guidelines were used to estimate carbon stock for some of the land/forest classes where country-specific data do not exist. Also, allometric equations for minor forest classes applied ones from neighboring country (i.e. Vietnam). Having improved set of country-specific carbon stock data and allometric equation shall contribute to reducing the uncertainty of E/R factors.

#### 3) Others

➤ Inclusion of non-CO2 gases emission from shifting cultivation and forest fire
Shifting cultivation is an important source of emission in Lao PDR. Although quantification of such
emission was tested during the FREL/FRL construction process, due to the lack of reliable data (AD
and E/R factors including specific combustion factor for shifting cultivation), non-CO2 gas emission

from shifting cultivation and consequent uncontrolled spreading of fire are not accounted in the current FREL/FRL. Although exclusion of such non-CO2 gases (mostly CH4 and N2O) are considered as conservative, Lao PDR will consider this as one area for technical improvement in the future.

#### Inclusion of dead wood (DW) as a carbon pool

The 2<sup>nd</sup> NFI measured DW for the five natural forest classes (i.e. EG, MD, CF, DD and MCB) which accounts for approximately 60% of the forest land (including RV), but not for the RV class. Therefore, the data on DW is considered incomplete, and partial inclusion of DW may result in inconsistent estimation and causing possibility of overestimation. Although exclusion of DW is considered as conservative, Lao PDR will consider this as one area for technical improvement in the future.

#### Measurement of emissions from forest degradation by selective logging

As emissions from forest degradation by selective logging is difficult to measure in the current remote sensing capacity of Lao PDR, alternative approach (i.e. estimate the emissions from the tree stumps recorded in the 2<sup>nd</sup> NFI) was applied. For maintaining consistency between the FREL/FRL and MRV, repetition of the same survey is needed. However, depending on the frequency of future measurements and reporting, repetition of the same survey may not be the most sustainable option. There are some initiatives in the country to measure emissions from forest degradation by selective logging through advanced remote sensing techniques. If such options prove reasonable, Lao PDR would consider adopting such options.

- Avoidance of double-counting of emissions and removals with other GHG mitigation initiatives Currently, two GHG mitigation initiatives are registered under the Verified Carbon Standard (VCS)<sup>30</sup> and being implemented in the country:
  - VCS Project ID 1684 "Mitigation of GHG: Rubber based agro-forestry system for sustainable development and poverty reduction in Pakkading, Bolikhamsay Province": a project to develop rubber plantation in Bolikhamsay province. The project has an area of 969.20ha, which expects to sequestrate approximately 1,107,495 tCO2e during its 30 year project period from 2008-2037 (36,916 tCO2e/year), and;
  - VCS Project ID 1398 "Reducing Emissions from Deforestation and Carbon Enhancement in Xe Pian National Protected Area": a project to provide sustainable long-term finance for an effective management of the Xe Pian National Protected Area (NPA) in Champasack province, in order to avoid deforestation and enhance carbon stocks. The Project Area presents an extent equal to 141,963 ha of the Xe Pian NPA, however, excluding the core parts of the NPA equivalent to 51,892 ha, which expects to sequestrate approximately 5,735,413 tCO2e during its 30 year project period of 2014-2043 (191,180 tCO₂e/year), approximately 0.65 million tCO₂e during its 1st baseline period (10 years) from 2014-2024 (64,981 tCO2e/year).

In addition, Lao PDR is in a process of applying for the Carbon Fund under the Forest Carbon Partnership Facility (FCPF)<sup>31</sup>. This is a sub-national scale project which targets six Northern provinces of Lao PDR, with the expected result-based payment period from 2019 to 2015. Considering the very closely associated reference levels and accounting systems applied for the Carbon Fund ERPD with this current submission, the Emissions Reduction Program of Lao PDR is considered a nested project of the national REDD+ program.

These activities will be tracked and recorded in a registry (to be developed), which will be part of the national forest monitoring system (NFMS) linking to the geo-spatial database.

.

<sup>30</sup> http://www.v-c-s.org/

<sup>&</sup>lt;sup>31</sup> The Final version of the Emission Reduction Program Document was submitted to the FCPF Carbon Fund on 18 May 2018. The ERPD is subject to changes in the course of assessment and negotiation.

#### **7.2.** Consistency with national GHG-Inventory

#### **National GHG-Inventory**

Lao PDR has so far submitted two National Communications (NC) to the UNFCCC:

- The 1st National Communications in year 2000 with year 1990 as the base year for the GHG Inventory
- The 2<sup>nd</sup> National Communications in year 2013 with year 2000 as the base year for GHG Inventory

Currently, the government is preparing the 3<sup>rd</sup> National Communication as well as the 1<sup>st</sup> Biennial Updating Report (BUR) with the support of UNEP/GEF. The overview is provided in the table below.

Table 37: Summary of plan for the NC and BUR

	3 <sup>rd</sup> National Communication	1 <sup>st</sup> Biennial Updating Report
Target date of	January 2019	January 2019
submission		
Reporting year	2010	2014
IPCC Guideline	IPCC 2006 in combination with	IPCC 2006 in combination with IPCC
generally applied	IPCC 1996 for some areas which	1996 for some areas which have
	have limited data	limited data
LULUCF data	AD from DOF	AD from DOF
	EF/RFs from DOF	EF/RFs from DOF

As seen from the table above, generally the data from DOF, which are the data used for the construction of national FREL/FRL agreed to be used in the GHG Inventory, acknowledging that they are the best available data which meets the standard of IPCC 2006 AFOLU.<sup>32</sup> However, the details need to be closely coordinated in order to avoid possible inconsistencies, and also to be transparent and accountable for explaining the relationship between the GHG Inventory and the FREL/FRL.

#### Measures to maintain consistency

The GHG Inventory Division of Department of Climate Change (DCC) under MONRE is responsible for coordinating the compilation of the GHG Inventory, and also acts as the national focal point to the UNFCCC. Therefore, coordination with the DCC will be important to maintain consistency between FREL/FRL and the GHG Inventory (and the future MRV).

Several avenues exist that will facilitate this process:

- The DCC is one of the members of the REL/MRV TWG. All the issues related to REL and MRV are discussed, technically reviewed and endorsed by the TWG before the final decision is made by the Government. Harmonization between national FREL/FRL the GHG Inventory is listed as one of the tasks of the TWG, the issue has been, and will continue to be discussed through this coordination mechanism.
- The Deputy Director of DDC is a member of the National REDD Task Force (NRTF). The NRTF is responsible for endorsing the issues related to REDD+, including the REL.
- Under the coordination of DCC, a Task Force for the 3<sup>rd</sup> NC and the 1<sup>st</sup> BUR has been established as an ad hoc committee to prepare the GHG Inventory. Staff from FIPD, who are

<sup>&</sup>lt;sup>32</sup> The 1st and 2nd National Communications applied the IPCC Revised Guideline for National GHG Inventory 1996.

- the members of the FREL/FRL drafting team, are assigned as the member of the GHG Inventory Task Force, and can bridge REDD+ and the GHG Inventory.
- Supporting development partners are pro-actively raising this issue in various venues, to facilitate the collaboration between DOF and DCC.

# 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**

January 2018

Department of Forestry
Ministry of Agriculture and Forestry, Lao PDR

### **Table of Contents**

1.	OBJ	ECTIVES	1
2.	ME	THODOLOGY	2
	2.1	Mapping frequency	2
	2.2	Forest definition and land/forest classification system	3
	2.3	Development of the Forest Type Maps 2005, 2010 and 2015	5
	2.3.1	Satellite imagery used	5
	2.3.2	Technical process	5
	2.4	Stratification of land/forest classes	. 15
	2.5	Sources and sinks selected	. 20
	2.6	Design-based area estimation of Activity Data	. 23
	2.6.1	Sampling design	. 24
	2.6.2	Response design	. 25
	2.6.3	Creation of error matrix	. 28
	2.6.4	Results of design-based estimation of Activity Data	. 28
	2.7	Map accuracy and uncertainty of activity data	. 30
3.	CON	ICLUSIONS AND AREAS FOR FUTURE IMPROVEMENT	. 32
.:	at af	Tablas	
LI		<b>Tables</b> ble 1: Summary of the definition of "Current Forest" and "Potential Forest" o	۰ŧ
	iak	Lao PDR	
	Tak	ole 2: National level classification system of Lao PDR with IPCC definition on land use categories	1
	Tak	ole 3: Satellite images used for the development of Forest Type Maps	
		le 4: Accuracy assessment of forest and non-forest	
		ble 5: Accuracy assessment of land/forest classes	
		ole 6: Initial Forest Cover Change Matrix 2005 - 2010 ole 7: Initial Forest Cover Change Matrix 2010 - 2015	
		ole 8: Patterns of illogical changes	
		ole 9: Areas of land/forest classes from Forest Type Map 2005, 2010 and 201	
			. 15
	Tak	le 10: Land/forest classes and stratification	. 16

	Table 11: Area and percentage per stratum for 2005, 2010 and 2015	20
	Table 12: Sampling design per source/sink 2005 - 2010	
	Table 13: Sampling design per source/sink 2010 - 2015	
	Table 14: Error matrix per source/sink 2005 - 2010	
	Table 15: Error matrix per source/sink 2010 - 2015	
	Table 16: Areas per source/sink 2005 - 2010	
	Table 17: Areas per source/sink 2003 - 2010	
	•	
	Table 18: Activity Data 2005 - 2010	
	Table 19: Activity Data 2005 – 2010: annual amount of change	
	Table 20: Activity Data 2010 - 2015	
	Table 21: Activity Data 2010 – 2015: annual amount of change	
	Table 22: Map accuracy and uncertainty of Activity Data 2005 - 2010	
	Table 23: Map accuracy and uncertainty of Activity Data 2010 - 2015	30
List	t of Figures	
	•	
	Figure 1: Overview of the Forest Type Map development process	
	Figure 2: Comparison of pixel-based classification and object-based class	sification 6
	Figure 3: Workflow for the development of Forest Type Map	8
	Figure 4: Slash-and-burn cycle and land/forest classes	9
	Figure 5: Forest Type Map 2005	12
	Figure 6: Forest Type Map 2010	13
	Figure 7: Forest Type Map 2015	14
	Figure 8: Stratified Forest Type Map 2005	17
	Figure 9: Stratified Forest Type Map 2010	18
	Figure 10: Stratified Forest Type Map 2015	
	Figure 11: Sources and sinks associated with REDD + activities	
	Figure 12: Sources and Sinks Map 2005 - 2010	
	Figure 13: Sources and Sinks Map 2010 - 2015	
	Figure 14: Example of reference data design using Collect Earth	
List	t of Boxes	
	Box 1: International support related to the development of Activity Dat	a 7
	Box 2: Challenges related to the classification of land under shifting cult	
	DOX 2. Challetiges related to the classification of faild under Silliting Cult	ivation 9

#### **Acronyms**

AD Activity Data B Bamboo

CF Coniferous Forest

DBH Diameter at Breast Height
DD Dry Dipterocarp Forest
DOF Department of Forestry

EG Evergreen Forest

FCPF Forest Carbon Partnership Facility
FIM Forest Information Management Project
FIPD Forestry Inventory and Planning Division

FREL Forest Reference Emission Level

FRL Forest Reference Level

GHG Greenhouse Gas

GIS Geographic Information System

IPCC Intergovernmental Panel on Climate Change

IT Information Technology

Lao PDR Lao People's Democratic Republic

M Million (when used for expressing units)

MAF Ministry of Agriculture and Forestry

MCB Mixed Coniferous Broadleaved Forest

MD Mixed Deciduous Forest

MRV Measurement, Reporting and Verification

NFI National forest Inventory

NFMS National Forest Monitoring System

OA Other Agriculture

P Plantation

REDD+ Reducing Emissions from Deforestation and forest Degradation plus the

conservation of forest carbon stocks, sustainable management of forests and

enhancement of forest carbon stocks

RV Regenerating Vegetation

UC Upland Crop

UNFCCC United Nations Framework Convention on Climate Change

#### 1. OBJECTIVES

The objectives of this report is to outline the process and result regarding the production of Activity Data (AD) for the estimation of Forest Reference Emission Level/Forest Reference Level (FREL/FRL) for Lao PDR. The report describes the two main areas of work, namely:

- 1) Development of Forest Type Maps of Lao PDR for years 2005, 2010, 2015<sup>1</sup>; 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 report only discuss the emissions and removals estimated by the use of spatially explicit AD. The emission from forest degradation by selective logging is estimated by proxy-based approach, therefore, not include in this report.

<sup>&</sup>lt;sup>11</sup> The maps are officially referred to as the "maps of 2005, 2010, and 2015"; and the change analysis are correspondingly referred to as covering for the periods of "2005-2010 and 2010-2015". However, it is noted that these maps were actually produced with satellite imageries from the dates of:

<sup>&</sup>quot;2005 map": Oct. 2004 - Apr. 2006;

<sup>&</sup>quot;2010 map": Nov. 2010 - Mar. 2011;

<sup>&</sup>quot;2015 map": Nov. 2014 - Feb. 2015.

Corresponding to the dates of these satellite images, the actual change analysis is for the 6-year period of 2005-2011 and the 4-year period of 2011-2015. For the remainder of this report and other official documentation, the maps and change analysis periods reference the official names based on uniform 5-year periods, but, needs to be understood that the actual analysis applied is not uniformly for each five years.

#### 2. METHODOLOGY

First, the Forest Type Maps 2005, 2010, 2015 for each province in the Lao PDR were developed. Based on the Forest Type Maps, initial Forest Change Maps and Forest Change Matrices were developed. Importantly, Forest Type Maps are developed applying the 'Level 2' of land/forest classification system, and then further stratified into the five land/forest strata. The stratified Forest Type Maps are overlaid to create second Forest Cover Change Maps and Forest Cover Change Matrices to derive the AD.

#### Box 1: International support related to the development of Activity Data

The FTMs were developed by the Forest Inventory and Planning Division (FIPD) of the Department of Forestry (DOF) under the Ministry of Agriculture and Forestry (MAF), by applying a consistent classification system, and based on past and on-going technical and financial support among six different projects as listed below.

Forest Information Management Project (FIM) (2010 - 2012) funded by JICA supported the construction of infrastructure required for remote sensing work in FIPD/DOF, such as remote sensing hardware, remote sensing software, server, internet and LAN network. SPOT4 / 5 MS imagery for year 2005 was procured through this project, which was then used in the development of the early version of Forest Type Map (FTM) 2005; ALOS, SPOT 5, RapidEye imagery for year 2010 was procured, which was then used for the development of early version of FTM 2010. In addition, an early version of FTM 2000 was developed by using Landsat imagery.

Forest Preservation Program (FPP) (2011 – 2015) funded by Japan, procured the RapidEye imagery for year 2015 through cost-sharing with FCPF Readiness Project and SUFORD-SU, which was then used in the development of FTM 2015.

Capacity Development Project for Establishing National Forest Information System for Sustainable Forest Management and REDD (NFIS) (2013 - 2015) under JICA succeeded the FIM project and developed the FTM 2010 as the benchmark map for producing the FTM 2005 and 2000 (however, note that the reference period of the RL of Lao PDR is 2005-2015, thus does not directly employ the results under this project).

Sustainable Forest Development – Scaling Up Phase (SUFORD-SU) (2013 - 2018) jointly funded by Finland and the World Bank FIP, procured the RapidEye imagery for year 2015 through cost-sharing with FPP and FCPF Readiness Project, which was then used in the development of FTM 2015. The project also technically supported the forest mapping of the Production Forest Areas (the forest type which the project targets) for the FTM 2010 and FTM2015, in close collaboration with NFIS and F-REDD Project in order to maintain the consistency in entire mapping.

Forest Carbon Partnership Facility -Readiness Project (FCPF Readiness Project) (2014 – 2017) (additional fund of USD 4.6 million and extension till 2020 committed) funded by the World Bank, procured the RapidEye imagery for year 2015 through cost-sharing with FPP and SUFORD-SU, which was then used in the development of FTM 2015.

Sustainable Forest Management and REDD+ Support Project (F-REDD) (2015 – 2020) funded by JICA further revised and finalized the FTM 2010, 2005 and 2000 developed under the support of NFIS, and newly developed the FTM 2015 by using the FTM 2010 as the benchmark. Each of the FTMs was assessed in its accuracy level. Forest change matrices for 2005-2010 and 2010-2015 were developed and uncertainty of changes was assessed, which were used as the source of AD.

#### 2.1 Mapping frequency

The AD was developed for two time periods: 2005-2010; and 2010-2015. Availability of official dataset which covers the Lao PDR was the ultimate reason of selecting the two time periods. Some background in arriving at this decision is presented below:

- 1) In the early stages of REDD+ readiness, while preparing towards submission of the Readiness Package Proposal to the FCPF, GoL consulted strategic options regarding the FREL/FRL and how to prepare necessary data including AD. It was agreed that a national wall-to-wall map with 2010 as the benchmark and dating back with 5-year intervals (i.e. 2005, 2000) would be appropriate. This was considered reasonable also from the perspective of the year 2000 being around the time when new major trends in land-use were observed to be emerging in the country;
- Through the FIM project (above) satellite imagery and technical support was provided to the GoL to initiate the mapping in 2010;

3) Although not yet realized, GoL's intentions to carry out the National Forest Inventory (NFI: field-based forest survey) every 5 years were expressed, thus, wall-to-wall mapping with 5-year interval was considered appropriate to cross-reference; and

As large part of Lao PDR's landscape is shifting cultivation, a 5-year interval was deemed as the minimum interval to capture resulting land/forest use changes.

#### 2.2 Forest definition and land/forest classification system

#### Forest definition

According to the Land Law (2003) and Forestry Law (2007), forest and forest resources in Lao PDR occur in lands that are designated by the Government as forest lands, and in areas outside forest lands, and includes stocked and temporarily un-stocked forests.

The land and forest classification system of the country applies two levels of classification, namely, Level 1 consisting of seven classes including "Current Forests" and "Potential Forests" among others, and Level 2 which further classifies the "Current Forest" class under Level 1 into five natural forest and one plantation forest classes. The land classification system is illustrated in Table 8.2.b below. The carbon accounting approach applied in the national FREL/FRL and the RL for the ER Program uses both "Current Forest" and "Potential Forest" classes as corresponding to the IPCC forestland category.

Lao PDR has applies a definition for Current and Potential forests respectively, a national definition of forests, for which a summary is shown in the following Table 1. This definition is used also in the construction of the proposed FREL/FRL.

Table 1: Summary of the definition of "Current Forest" and "Potential Forest" of Lao PDR

Current Forest	Potential Forest
Stand DBH: minimum of 10cm Crown density: minimum of 20% Minimum area of 0.5ha.	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, and not permanently being used for other purposes (i.e. residential, agriculture etc.). It also does not include Upland Crop (UC), despite its common nature as a cropping stage of shifting cultivation cycle, based on de facto land-use at the time of observation

Note: The main reason of applying the DBH threshold for the "Current Forest" definition, over the more conventional height threshold is to facilitate the accounting of forest fallow (typically classified as RV) as Potential Forest (and not Current Forest). Such regenerating forests are often covered by small diameter trees over 5.0m in height. In the context of the country, such lands should not be considered as Current Forest because repeated disturbance may maintain such land in an understocked condition for an indeterminate period of time, and therefore, are better managed when classified as Potential Forests. By applying the definition of a minimum tree DBH of 10 cm, forest land covered with small diameter trees which would have been classified as "Current Forest" under a height threshold definition can be excluded from the NFI survey measurements. This DBH criteria applies to the trees to be measured during the NFI. Thereby, where there are no trees meeting this criterion, the NFI measurements would not be applied.

The main reason for the 20% crown density threshold for the "Current Forest" definition is to do with the national circumstances of trees commonly occurring in rice paddy landscapes in the flatland areas. In order to avoid misinterpretation of these paddy lands as forests, particularly through remote sensing – as such lands often have canopy cover of over 10% – the 20% crown density threshold has been adopted, for Current Forests.

This definition was used for the past two National Communications on Climate Change, and has been agreed to be used for the future national Greenhouse Gas (GHG) inventory starting with the Third National Communication which the GoL plans to submit to the UNFCCC in early 2019.

#### **Land/forest classification system**

The land/forest classification system of the country applies two levels of classification, including Level 1 consisting of seven classes including "Current Forest" and "Potential Forest" among others, and Level 2 which further classifies the Level 1 current forest class into six natural and plantation classes. The relation between the national land/forest classification system and the land-use category definition of the IPCC is illustrated in Table 2 below.

When Lao PDR initiated the development of its national Forest Type Maps (wall-to-wall maps of the entire territory) under the context of REDD+ around 2010, the government and stakeholder first reviewed the land/forest classification system to be applied for the mapping.

Table 2: National level classification system of Lao PDR with IPCC definition on land use categories

IPCC Definition	Nati	onal level classification system	
IPCC Definition	Level 1	Level 2	
		Evergreen Forest	EG
		Mixed Deciduous Forest	MD
	Current Forest	Dry Dipterocarp Forest	DD
Forest Land	Current Forest	Coniferous Forest	CF
Forest Land		Mixed Coniferous and Broadleaved Forest	MCB
		Forest Plantation	Р
	Potential Forest	Bamboo	В
	Potential Forest	Regenerating Vegetation	RV
		Savannah	SA
Grassland	Other Vegetated Areas	Scrub	SR
		Grassland	G
		Upland Crop	UC
Cranland	Cropland	Rice Paddy	RP
Cropland	Cropland	Other Agriculture	OA
		Agriculture Plantation	AP
Settlement	Settlement	Urban Areas	U
Otherland	Other Land	Barren Land and Rock	BR
Other land	Other Land	Other Land	0
Motland	Above-ground Water	River (Water)	W
Wetland	Source	Wetland (Swamp)	SW

An important point was to ensure the classification system is in harmony with the land-use category definition of the IPCC in order to maintain consistency between the REDD+ and GHG inventory while meeting national needs in a variety of applications. Another was to determine how to categorize the temporarily un-stocked forests ("regenerating vegetation: RV") and upland crop (UC) in the classification system. This reflects the unique situation of forests and forest use in the country, and

in particular, the prevalence of pioneering and shifting cultivation, and presence of vast areas of forest fallow. This land-use is seen throughout the country where a significant area is covered under forest fallow stages of shifting cultivation, regenerating through natural vegetative succession and in and out of temporarily un-stocked states.

UC and RV are predominately considered to be stages of the shifting cultivation cycle, and these lands are considered to re-grow and recover through natural vegetative succession. Through intensive discussions within DOF and with stakeholders on whether to classify these under the IPCC land use category of "Forest Land" or "Cropland", it was concluded that for the purpose of REDD+, in line with the IPCC definition, to classify RV under "Forest Land" as they are "...a vegetation structure that currently fall below, but in situ could potentially reach the threshold values used by a country to define the Forest Land category..." (IPCC, 2006) and classify UC under "Cropland" as they are used, even if temporarily, for cropping at the time of mapping.

#### 2.3 Development of the Forest Type Maps 2005, 2010 and 2015

#### 2.3.1 Satellite imagery used

The satellite imagery used for the development of FOREST TYPE MAPs for years 2005, 2010 and 2015 are summarized in following Table 3.

**Table 3: Satellite images used for the development of Forest Type Maps** 

Name	SPOT4 / 5 MS	RapidEye	RapidEye
Year	2005	2010	2015
Observation	From Oct. 2004 to Apr.	From Nov. 2010 to Mar.	From Nov. 2014 to Feb.
term	2006	2011 for Forest Type Map	2015 for Forest Type Map
		2010	2015
Number of	114	146	94
scenes			
Resolution	10m	5m	5m
Bands	Band1: Green	Band1: Blue	Band1: Blue
	Band2: Red	Band2: Green	Band2: Green
	Band3: NIR	Band3: Red	Band3: Red
	Band4: SWIR	Band4: Rededge	Band4: Rededge
		Band5: NIR	Band5: NIR

The mapping standards were determined considering various factors, such as the appropriateness of mapping scale, resolution of satellite imagery, time resources. The mapping scale was decided to be 1/100,000, and the minimum mapping unit of 0.5 ha was consistently used for developing the Forest Type Maps.

#### 2.3.2 Technical process

#### **Overview of the process**

The general process for the development of Forest Type Map 2005, 2010 and 2015 is described in Figure 1. In order to secure time-series consistency among the maps of different years, and also taking into account costs and map quality, first, the Forest Type Map 2010 was developed as the benchmark map. Next, the satellite imagery of year 2010 was compared with the satellite imagery of years 2005 and 2015 respectively to extract the changes over the two respective periods (i.e. change detection). Then, the changed areas were overlaid with the Forest Type Map 2010 to develop Forest Type Map 2005 and 2015.

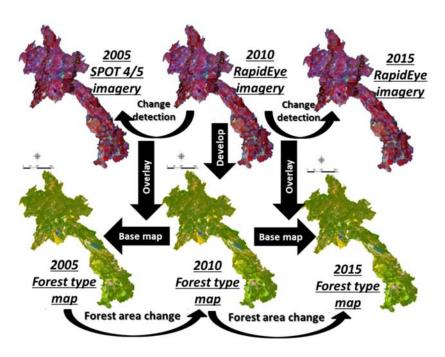


Figure 1: Overview of the Forest Type Map development process

For the development of Forest Type Map 2010, object-based classification was applied instead of pixel-based classification, in order to reduce the occurrence of noise ('slivers') (Figure 2). This helps to reduce 'slivers' arising when extracting the changes from two different maps (Forest Type Map 2010 and 2005; Forest Type Map 2010 and 2015), and also allows efficient 'snapping' of the polygon boundaries of other two years to the Forest Type Map 2010.

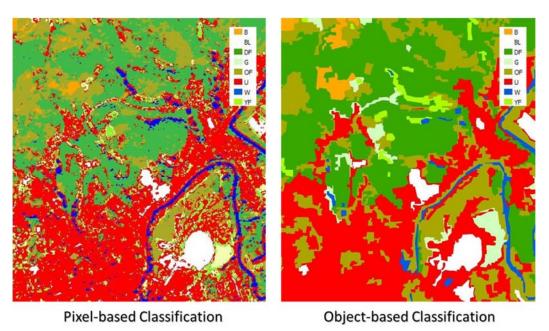


Figure 2: Comparison of pixel-based classification and object-based classification

#### **Data processing and classification**

First, each satellite imagery was pre-processed. For year 2005, SPOT4/5 MS imagery was orthorectified and then mosaicked. For years 2010 and 2015 where RapidEye imagery were used, absolute

position and relative position accuracy were improved by ortho-rectifying and using ground control points collected from the entire country as well as from very high resolution satellites. Afterwards they were mosaicked using the same methods with the year 2005 SPOT4/5 MS imagery.

Normalized Difference Vegetation Index (NDVI) was created for every processed imagery. Color enhancement was carried out for each mosaic imagery to evenly adjust the color tone to the extent possible, and minimize the effect of differences to the interpretation results.

Next, segmentation was carried out in order to create the 'object' units for object-based classification. During this step, the scale parameter was determined through trial-and-error, to find the most appropriate parameter for each satellite imagery with different resolution, so that the objects units could be unified as necessary and sufficient.

Then, the Forest Type Map 2010 was developed through two steps: first classified by supervised classification, then corrected by visual (manual) interpretation.

#### **Change detection**

By using Forest Type Map 2010 as the benchmark, Forest Type Map 2005 and 2015 were developed though change detection method. When applying change detection method, automated extraction of changes was explored. However due to the differences in the imaging conditions among images, such as sun direction, shooting angle and shooting season, it was difficult to apply automated methods with available software. Thus, the option was taken to identify and classify the changes through visual (manual) interpretation.

To control the quality of the visual (manual) interpretation, a three-fold control process was introduced.

- Step 1: interpretation by FIPD remote sensing engineers. Each engineer was assigned to a specific region (a group of provinces) where his/her specialized knowledge can be utilized and further accumulated.
- Step 2: quality check by FIDP senior remote sensing engineers. Any possibilities of misinterpretation and errors were returned to the Step 1 engineer for re-checking.
- Step 3: sample-based random quality check by external international remote sensing engineers from F-REDD Project. Any possibilities of misinterpretation and errors were returned to the Step 1 engineer for re-checking.

As widely recommended, remote sensing exercise was combined with nation-wide ground truth survey to improve and verify the map quality, and also to build the interpretation capacity of the FIPD remote sensing engineers involved in the task. The results of ground truth survey were organized into a system for improvement, such as establishing interpretation standards for each satellite imagery and classification item, preparation/updating of interpretation cards, then shared among the interpretation team.

To avoid overestimation of emissions and removals, only the cases which could be interpreted as 'obvious change' were extracted. The detailed work flow is shown in Figure 3.

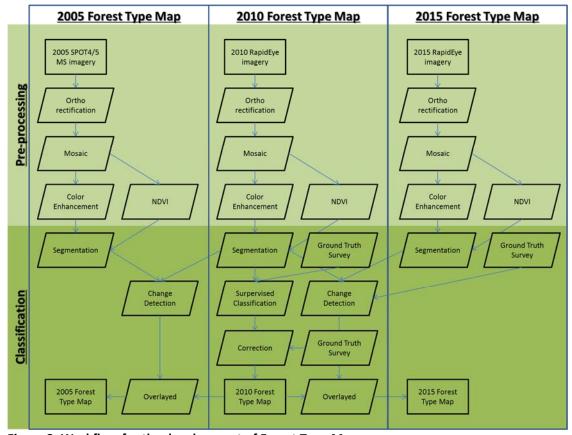


Figure 3: Workflow for the development of Forest Type Map

#### Challenges related to the classification of land under shifting cultivation

A technical challenge faced throughout the forest mapping exercise was to accurately and consistently distinguish the Upland Crop (UC), Regenerating Vegetation (RV) and Mixed Deciduous Forest (MD).

As a supplementary measure to improve the classification accuracy and time-series consistency for UC, RV and MD classes (considered to be associated with shifting cultivation), the FIPD team made corrections to the Forest Type Map classes based on the years since the land was slashed and burnt.

This involved a survey of the number of years of fallow required to regenerate to meet the forest definition (i.e. the threshold year). The survey used the annual vegetation loss dataset by Hansen et al <sup>2</sup> to detect the year of loss on forest loss plots, then ground truth and measure the crown cover to find whether it has reached the status as 'forest'. The results of survey showed that the threshold number of years for a RV fallow to reach the forest threshold was on average seven years. By adding one year for cropping (classified as "UC"), it was assumed that a land slashed and burnt would regenerate into forest status in eight years (see the "RD Survey" Report <sup>3</sup> for details).

<sup>&</sup>lt;sup>2</sup> Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. (2013) "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850–53. Data available on-line from: http://earthenginepartners.appspot.com/science-2013-global-forest.

<sup>&</sup>lt;sup>3</sup> DOF, et al. (2017) "Development of a Lao-specific Equation for the Estimation of Biomass of 'Regenerating Vegetation' and Determination of the Threshold Years for its Regeneration into Forest. <a href="http://dof.maf.gov.la/en/home/">http://dof.maf.gov.la/en/home/</a>

#### Box 2: Challenges related to the classification of land under shifting cultivation

The total area of these three land/forest classes account for nearly 70% of the land of Lao PDR and over 80% of the land of the ER-P AA. Due to the prevalence of shifting cultivation in Lao PDR and particularly in the northern region (ER-P target area), large areas of land are shifting between these three different land/forest classes. Accurate interpretation of the transition events from UC (i.e. non-forest land) to RV (i.e. forest land temporarily un-stocked and does not meet the definition as forest) and then to MD, through satellite imagery presents a technical challenge. The classification of these land/forest classes can have significant impact on uncertainty.

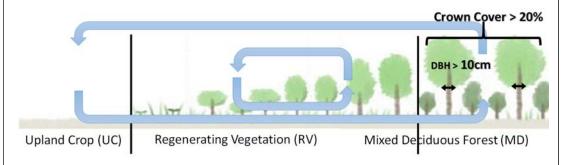


Figure 4: Slash-and-burn cycle and land/forest classes

Among the stages of shifting cultivation, UC is the stage of the land immediately after being slashed-and-burnt for cropping, and is relatively easy to classify due to the lack of, or reduced, vegetation cover. RV and MD are continuous phases of regeneration in many cases, and old RV and young MD have very similar color tone and texture on satellite imagery, thus, distinguishing the two in a single satellite imagery is technically challenging.

However, the two issues below related to the use of dataset from Hansen et al. were taken into account while maintaining conservativeness in estimates, and only the plots (polygons) which clearly satisfy the criteria above were revised:

- 1) The Hansen et al. dataset includes vegetation loss occurring outside forest land (e.g. on agriculture land). Therefore, if a land parcel (polygon) is interpreted as UC for more than 10 years (continuously interpreted as UC over the 2 time periods of 2005-2010 and 2010-2015) it was determined as permanent agricultural land and the classification of the latter year was revised to Other Agriculture (OA) class; and
- 2) The Hansen et al. dataset does not identify repeated loss events, thus, repeated loss could be under-estimated. Considering 8 years as the standard number of years for forest regeneration (i.e. 1 year as UC and 7 years under fallow), only the MD plots (polygons) where vegetation loss was confirmed in the past one to eight years were revised to RV (with an assumption that land will not regenerate into MD class in less than eight years).

#### Accuracy assessment of the Forest Type Map 2010

After the Forest Type Map 2010 was developed, an accuracy assessment was undertaken as in the tables below. The overall accuracy for classification of "forest" and "non-forest" was 90.9% (Table 4), and the overall accuracy of classification among the land/forest classes (eight forest land classes and aggregation of all non-forest lands) was 74.0% (Table 5).

Table 4: Accuracy assessment of forest and non-forest

	2010		Referenc	e data	
		Forest	Non-forest	Total	U.A
	Forest	1631	158	1789	91.2%
Man	Non-forest	34	278	312	89.1%
Мар	Total	1665	436	2101	
	P.A	98.0%	63.8%		
Over	all Accuracy	90.9%			

Table 5: Accuracy assessment of land/forest classes

rabi	e 5: <i>F</i>	Accuracy as	ssessii	ient oi	ianu/i	orest	ciasses	•						
								R	eference	data				
							Forest	Land						
		2010				Curren	t Forest			Pote For	ntial est	Non- forest	Total	U.A
				EG	MD	DD	CF	МСВ	Р	В	RV		10141	
			EG	204	26	1					4		235	86.8%
			MD	51	656	13	3	12		4	73	34	846	77.5%
		Current	DD		7	84			1		4	13	109	77.1%
	ores.	Forest	CF		2	1	11	3			1		18	61.1%
	Forest Land		МСВ	1	4		1	8				1	15	53.3%
Мар	_		Р		2				8		3	5	18	44.4%
		Potential	В	2	9					4	5	1	21	19.0%
		Forest	RV	2	102	4	1	2	4	6	302	104	527	57.3%
		Non-forest			7	9			9	1	8	278	312	89.1%
		Total		260	815	112	16	25	22	15	400	436	2101	_
		P.A		78.5%	80.5%	75.0%	68.8%	32.0%	36.4%	26.7%	75.5%	63.8%		
	Overall Accuracy 74.0%													

#### **Development of initial Forest Change Maps**

From the draft Forest Type Maps developed above, initial Forest Change Maps for the period of 2005-2010 and 2010-2015 were generated to conduct initial analysis of forest change and collect "illogical changes" by overlaying the Forest Type Maps of the two different years. From the vector maps which recorded the forest changes for the period of 2005-2010 and 2010-2015, Forest Change Matrices were generated by exporting the attributes in the GIS, and using the Pivot Table tool of Microsoft Excel to sum up the area size of the changed polygons per each land/forest class.

Table 6: Initial Forest Cover Change Matrix 2005 - 2010

ha	2010	EF	MD	DD	CF	MCB	Р	В	RV	SA	SR	G	SW	UC	RP	OA	AP	U	BR	0	W	total
2005		11	12	13	14	15	16	21	22	31	32	41	42	51	61	62	63	71	72	80	81	
EF	11	2,612,407	1,827	0	0	0	185	6	886	0			0	279	466	973	21	0	0	54	1,066	2,618,169
MD	12	773	9,401,983	0	0	0	14,557	10,498	172,818	0		(	0	19,919	8,461	43,467	4,153	272	0	262	7,693	9,684,854
DD	13	0	32	1,214,850	0	0	18,413	0	4,857	104	99	(	0	2,377	14,071	13,296	2,854	432	0	443	178	1,272,006
CF	14	0	0	0	125,153	1	32	0	8,617	0			0	27	52	168	5	0	0	0	0	134,055
MCB	15	0	4	0	0	108,453	16	0	10,181	0		(	0	57	234	147	4	135	0	293	22,935	142,458
Р	16	0	0	0	0	0	22,874	0	543	0		(	0	13	100	281	66	0	0	2	1	23,880
В	21	0	0	0	0	0	93	65,490	3.275	0			0	15	0	117	0	0	0	0	0	68.989
RV	22	46	83,993	862	76	113	41,278	13,758	5,376,618	0			0	181,169	39,014	311,379	19,216	1,463	0	1,929	19,579	6,090,500
SA	31	0	0	0	0	0	79	0	0	102,800			0	845	683	1,303	115	28	0	9	0	105,861
SR	32	0	0	0	0	0	198	0	0	0	26,591	2		149	15	475	5	0	3	17	17	27,472
G	41	0	0	0	0	0	4,131	0	43	0		255,504	0	387	1,480	1,398	413	281	0	152	5,863	269,652
SW	42	0	0	0	0	0	89	0	0	0			9,824	19	38	370	23	5	0	0	57	10,425
UC	51	0	0	0	0	0	0	1,299	205,761	349	94	321	133	0	0	0	0	65	0	40	203	208,264
RP	61	0	0	0	0	0	2,702	43	14,995	0		(	0	0	1,135,429	16,627	611	5,726	0	1,449	2,946	1,180,530
OA	62	0	0	0	0	0	3,749	49	40,134	0			0	14	2,481	564,635	5,839	653	0	37	241	617,832
AP	63	0	0	0	0	0	1,628	0	1,985	0		(	0	0	0	31	48,653	0	0	0	1	52,297
U	71	0	0	0	0	0	0	0	65	0		(	0	0	0	0	0	64,237	0	53	0	64,355
BR	72	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	185,860	0	228	186,088
0	80	0	0	0	0	0	0	0	131	0		(	0	2	15	0	1	0	0	17,463	61	17,673
W	81	0	0	0	0	0	0	0	0	0		(	0	0	2	0	0	0	93	1	278,796	278,892
total		2,613,226	9,487,839	1,215,712	125.229	108.567	110.024	91.143	5.840.908	103.253	26.784	255,834	9.957	205.272	1.202.541	954,666	81.981	73.296	185,956	22,204	339.866	23,054,258

**Table 7: Initial Forest Cover Change Matrix 2010 - 2015** 

ha	2015	EF	MD	DD	CF	MCB	Р	В	RV	SA	SR	G	SW	UC	RP	OA	AP	U	BR	0	W	total
2010		11	12	13	14	15	16	21	22	31	32	41	42	51	61	62	63	71	72	80	81	
EF	11	2,605,557	355	13	0	0	48	0	825	0	0	0	0	2,601	55	3,305	1	20	0	411	36	2,613,226
MD	12	0	9,097,386	313	0	40	7,390	36	272,089	0	0	73	0	45,616	2,718	52,744	2,200	517	0	3,968	2,748	9,487,839
DD	13	0	10	1,187,781	0	0	15,238	0	540	74	0	4		210	5.426	3,818	1.364	323	0	841	83	1,215,712
CF	14	0	0	0	124,772	0	0	0	58	0		2		203	2	156	0	0	0	37	0	125,229
MCB	15	0	7	0	0	107,837	0	0	98	0	0	0		333	3	265	0	0	0	24	0	108,567
P	16	0	0	0	0	0	108,875	0	64	0	0	0	0	116	34	879	28	4	0	23	. 0	110,024
В	21	0	23	0	0	0	9	88,746	404	0		0		841	2	1,043	0	3	0	70	0	91,143
RV	22	0	107,254	91	0	3	3,324	95	5,542,984	0	0	107		88,261	4,800	82,373	929	1,060	0	3,059	6.567	5,840,908
SA	31	0	0	0	0	0	233	0	0	102,031	0	0		44	649	136	94	28	0	31	6	103,253
SR	32	0	0	0	0	0	4	0	0	0	26,603	0		54	23	22	0	12	66		0	26,784
G	41	0	0	0	0	0	0	0	0	0		254,172		581	118	857	0	28	0	73	5	255,834
SW	42	0	0	0	0	0	334	0	0	0	0	0	9,561	29	17	5		0	0	0	10	9,957
UC	51	0	0	0	0	0	0	21	204,505	5		4		0	0	0	0	292	0	333	109	205,272
RP	61	0	0	0	0	0	1,171	1	10,432	0	0	0	0	571	1,182,402	5,913	236	602	0	449	762	1,202,541
OA	62	0	0	0	0	0	1,197	0	39,449	0	26	13		10,320	3,289	899,003	223	245	0	601	301	954,666
AP	63	0	0	0	0	0	104	0	1,670	0		2		568	6	1,246	78,196	9	0	- 11	168	81,981
U	71	0	0	0	0	0	16	0	182	0	0	0		102	183	241	32	72,448	0	73	19	73.296
BR	72	0	0	0	0	0	0	0	0	0	6	0		0	0	0	0	0	185,945	0	5	185,956
0	80	0	0	0	0	0	23	0	279	0		0		68	120	229	3	47	137	21,230	68	22,204
W	81	0	0	0	0	0	0	0	0	0	0	0		0	53	334	0	0	9	53	339,417	339,866
total		2,605,557	9,205,036	1,188,198	124,772	107,880	137,965	88,900	6,073,581	102,110	26,637	254,376	9,561	150,519	1,199,903	1,052,569	83,306	75,638	186,157	31,289	350,304	23,054,258

In the initial Forest Change Matrices, all the changes which should not occur, either from ecological reason or within the period of 5 year, were identified as "Illogical changes" (see Table 8 below). Through this diagnostic check, all of these areas were double-checked and corrected. All of the changes which were unlikely to occur, although not definite, were double-checked and corrected as necessary.

**Table 8: Patterns of illogical changes** 

Tubic o. Fatternis of mogic			5																			
			EF	MD	DD	CF	MCB	Р	В	RV	SA	SR	G	SW	UC	RP	OA	AP	U	BR	0	W
			11	12	13	14	15	16	21	22	31	32	41	42	51	61	62	63	71	72	80	81
Evergreen Forest	EF	11	0	0	Δ	Δ	Δ	0	0	0	×	×	Δ	×	0	0	0	0	0	×	0	Δ
Mixed Deciduous Forest	MD	12	0	0	Δ	Δ	Δ	0	0	0	×	×	Δ	×	0	0	0	0	0	×	0	Δ
Dry Dipterocarp Forest	DD	13	×	Δ	0	Δ	Δ	0	0	0	0	0	Δ	×	0	0	0	0	0	×	0	Δ
Coniferous Forest	CF	14	×	×	×	0	0	0	0	0	×	×	Δ	×	0	0	0	0	0	×	0	Δ
Mixed Coniferous and Broadleaved Forest	MCB	15	×	Δ	×	0	0	0	0	0	×	×	Δ	×	0	0	0	0	0	×	0	Δ
Forest Plantation	Р	16	×	Δ	Δ	Δ	Δ	0	0	0	×	×	Δ	×	0	0	0	0	0	×	0	Δ
Bamboo	В	21	Δ	Δ	Δ	Δ	Δ	0	0	0	×	×	Δ	×	0	0	0	0	0	×	0	Δ
Regenerating Vegetation	RV	22	Δ	0	0	0	0	0	0	0	×	×	Δ	×	0	0	0	0	0	×	0	Δ
Savannah	SA	31	×	×	×	×	×	0	×	×	0	Δ	Δ	×	0	0	0	0	0	×	0	Δ
Scrub	SR	32	×	×	×	×	×	0	×	×	×	0	Δ	×	0	0	0	0	0	Δ	0	Δ
Grassland	G	41	×	×	×	×	×	0	×	×	×	×	0	×	0	0	0	0	0	×	0	Δ
Swamp	SW	42	×	×	×	×	×	0	×	×	×	×	×	0	0	0	0	0	0	×	0	Δ
Upland Crop	UC	51	×	×	×	×	×	0	0	0	0	0	0	0	0	0	0	0	0	×	0	Δ
Rice Paddy	RP	61	×	×	×	×	×	0	0	0	×	×	×	×	×	0	0	0	0	×	0	Δ
Other Agriculture	OA	62	×	×	×	×	×	0	0	0	×	×	×	×	Δ	Δ	0	0	0	×	0	Δ
Agriculture Plantation	AP	63	×	×	×	×	×	0	0	0	×	×	×	×	Δ	Δ	Δ	0	0	×	0	Δ
Urban	U	71	×	×	×	×	×	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	0	×	0	Δ
Barren Land and Rock	BR	72	×	×	×	×	×	×	×	×	×	Δ	×	×	×	×	×	×	×	0	×	Δ
Other Land	0	80	×	×	×	×	×	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	0	Δ
Water	W	81	×	×	×	×	×	×	×	×	×	×	Δ	Δ	×	Δ	Δ	×	×	0	Δ	0

X: illogical changes which should not occur

Δ: changes unlikely to occur, although not impossible

O: possible changes

#### **Forest Type Maps**

Figure 5, Figure 6 and Figure 7 show the final Forest Type Maps for years 2005, 2010 and 2015, and Table 9 shows the areas of land/forest classes calculated from these maps, for the respective years.

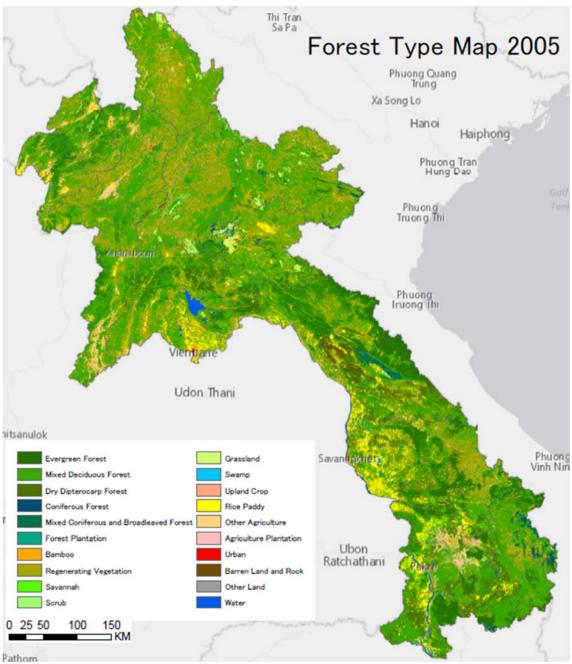


Figure 5: Forest Type Map 2005

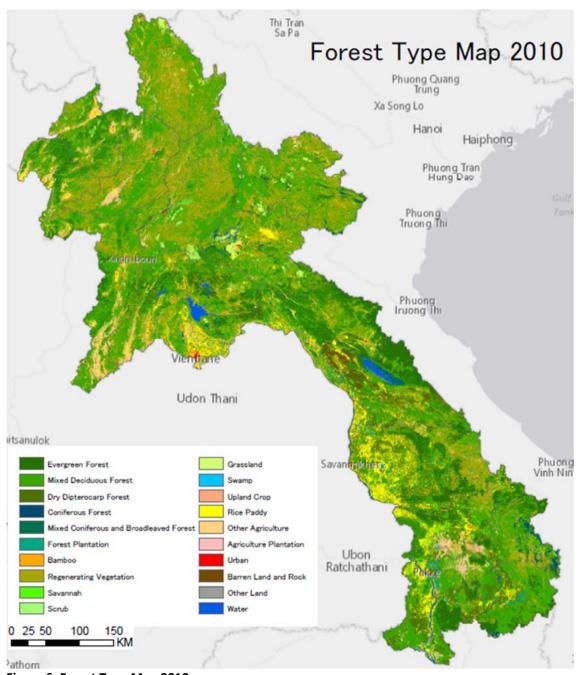


Figure 6: Forest Type Map 2010

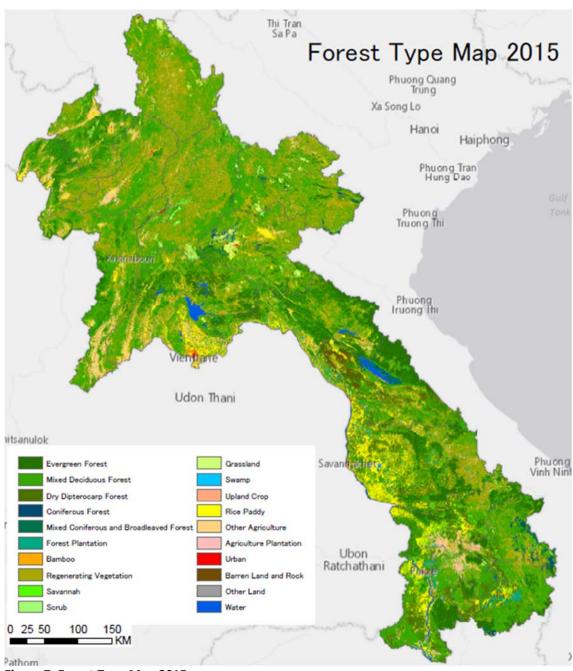


Figure 7: Forest Type Map 2015

Table 9: Areas of land/forest classes from Forest Type Map 2005, 2010 and 2015

Table 9. Areas of failu/for	cst clas	303 110111 1016	.st Type	•		-019	
				Area (ha), ra	itio (%)		
		2015		2010		2005	
Evergreen Forest	EG	2,605,557	11.3%	2,613,226	11.3%	2,618,169	11.4%
Mixed Deciduous Forest	MD	9,205,036	39.9%	9,487,839	41.2%	9,684,854	42.0%
Coniferous Forest	CF	124,772	0.5%	125,229	0.5%	134,055	0.6%
Mixed Coniferous and Broadleaved Forest	МСВ	107,880	0.5%	108,567	0.5%	142,458	0.6%
Dry Dipterocarp Forest	DD	1,188,198	5.2%	1,215,712	5.3%	1,272,006	5.5%
Forest Plantation	Р	137,965	0.6%	110,024	0.5%	23,880	0.1%
Bamboo	В	88,900	0.4%	91,143	0.4%	68,989	0.3%
Regenerating Vegetation	RV	6,073,581	26.3%	5,840,908	25.3%	6,090,500	26.4%
Savannah	SA	102,110	0.4%	103,253	0.4%	105,861	0.5%
Scrub	SR	26,637	0.1%	26,784	0.1%	27,472	0.1%
Grassland	G	254,376	1.1%	255,834	1.1%	269,652	1.2%
Swamp	SW	9,561	0.0%	9,957	0.0%	10,425	0.0%
Upland Crop	UC	150,519	0.7%	205,272	0.9%	208,264	0.9%
Rice Paddy	RP	1,199,903	5.2%	1,202,541	5.2%	1,180,530	5.1%
Other Agriculture	OA	1,052,569	4.6%	954,666	4.1%	617,832	2.7%
Agriculture Plantation	AP	83,306	0.4%	81,981	0.4%	52,297	0.2%
Urban	U	75,638	0.3%	73,296	0.3%	64,355	0.3%
Barren Land and Rock	BR	186,157	0.8%	185,956	0.8%	186,088	0.8%
Other Land	0	31,289	0.1%	22,204	0.1%	17,673	0.1%
Water	W	350,304	1.5%	339,866	1.5%	278,892	1.2%
Total		23,054,258	100%	23,054,258	100%	23,054,258	100%

#### 2.4 Stratification of land/forest classes

In order to reduce uncertainty of emissions and removals while balancing the accuracy of sampling and the cost/efforts required, the land/forest classification explained in Section 2.2 was further stratified into five strata as below and as summarized in Table 10:

- Evergreen Forest (EG) has distinctly high carbon stocks (200.00tC), thus, separated as an independent stratum Stratum 1 (expanse: 2,605,557ha, 11.3% of the total land area).
- Mix Deciduous Forest (MD), Conifer Forest (CF) and Mixed Coniferous and Broadleaved Forest (MCB) will form one stratum on the basis of similarity in carbon stocks per hectare (87.7tC, 92.6tC, 114.7tc). – Stratum 2 (expanse: 9,437,688ha, 40.9% of the total land area).
- Dry Dipterocarp Forest (DD) will form one stratum due to the difference in carbon stock from other forest classes (43.2tC), and also due to the fact that they are mostly distributed in the low-lands and prone to conversion to other land use – Stratum 3 (expanse: 1,188,198, 5.2% of the total land area).
- Plantation (P), Bamboo (B) and Regenerating Vegetation (RV) will form one strata on the basis of similarity in average carbon stock (37.2tC, 24.4tC, 17.4tC) and the limited area of P and B Stratum 4 (expanse: 6,300,445ha, 27.3% of the total land area).

• The remaining 12 non-forest classes will form one stratum – Stratum 5 (expanse: 3,522,370ha, 15.3% of the total land area).

Table 10: Land/forest classes and stratification

	Land/forest classes		Area (ha)	% of total	Strata
Level 1	Level 2			51. 25.	
	Evergreen Forest	EG	2,605,557	11.3%	1
	Mixed Deciduous Forest	MD			
	Coniferous Forest	CF	0 427 600	40.9%	2
Current Forest	Mixed Coniferous and Broadleaved Forest	МСВ	9,437,688	40.9%	2
	Dry Dipterocarp Forest	DD	1,188,198	5.2%	3
	Forest Plantation	Р			
Potential Forest	Bamboo	В	6,300,445	27.3%	4
Potential Polest	Regenerating Vegetation	RV			
Other Vegetated	Savannah	SA			
Areas	Scrub	SR			
Aicas	Grassland	G			
	Upland Crop	UC			
Cropland	Rice Paddy	RP			
Сторіани	Other Agriculture	OA	3,522,370	15.3%	5
	Agriculture Plantation	AP	3,322,370	15.570	3
Settlement	Urban Areas	U			
Other Land	Barren Land and Rock	BR			
Other Land	Other Land	0			
Above-ground	Wetland (Swamp)	SW			
Water Source	River (Water)	W			
Total			23,054,258	100%	

#### **Stratified Forest Type Maps**

Figure 8, Figure 9 and Figure 10 show the stratified Forest Type Maps for year 2005, 2010 and 2015 respectively, and Table 11 summarizes the area and percentage of each stratum for different years.

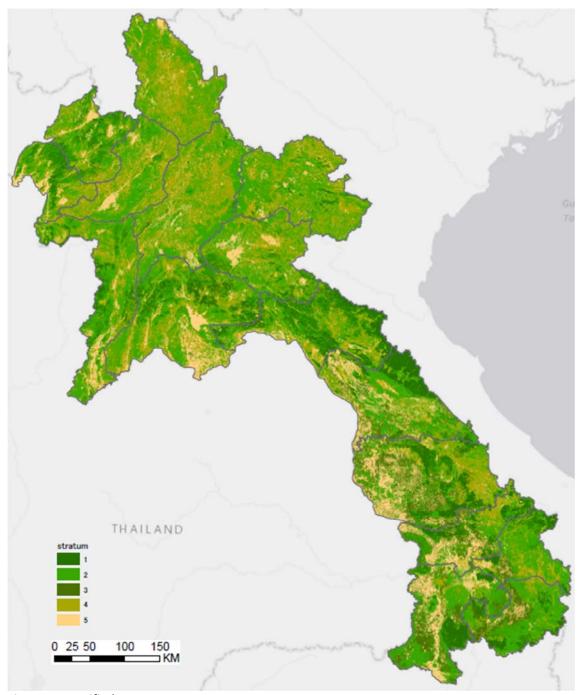


Figure 8: Stratified Forest Type Map 2005

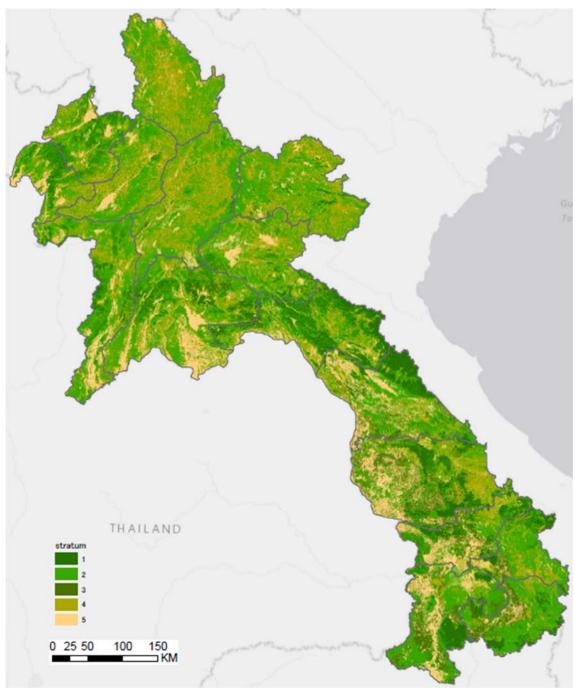


Figure 9: Stratified Forest Type Map 2010

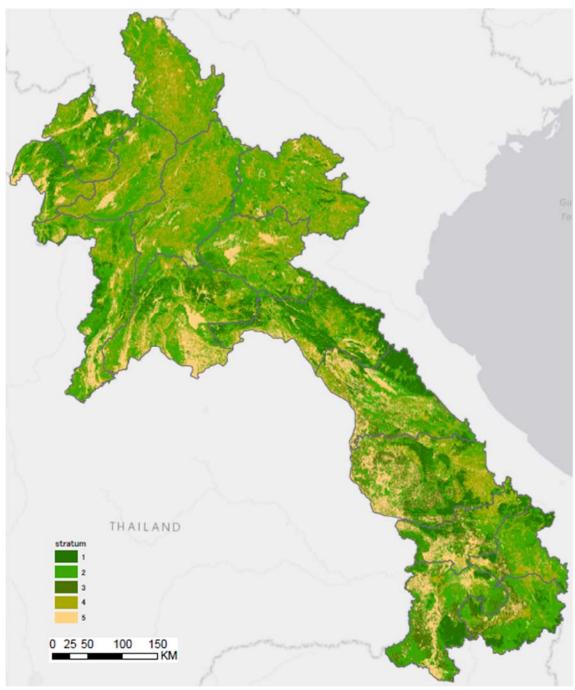


Figure 10: Stratified Forest Type Map 2015

Table 11: Area and percentage per stratum for 2005, 2010 and 2015

Unit: ha, percentage

	2015	%	2010	%	2005	%
Stratum 1	2,605,557	11.3%	2,613,226	11.3%	2,618,169	11.4%
Stratum 2	9,437,688	40.9%	9,721,635	42.2%	9,961,368	43.2%
Stratum 3	1,188,198	5.2%	1,215,712	5.3%	1,272,006	5.5%
Stratum 4	6,300,445	27.3%	6,042,075	26.2%	6,183,370	26.8%
Stratum 5	3,522,370	15.3%	3,461,610	15.0%	3,019,344	13.1%
Total	23,054,258	100%	23,054,258	100%	23,054,258	100%

#### 2.5 Sources and sinks selected

The emissions<sup>4</sup> and removals are estimated by first applying Emission Factors to the area estimates of the AD<sup>5</sup>. Then, the results were aggregated into the selected four (4) sources and sinks associated with the REDD+ Activities over two different periods (i.e. 2005-2010 and 2010-2015), which are:

- Emissions from Deforestation (DF), caused by loss of forest carbon stock due to conversion of a forest land stratum to non-forest land stratum;
- Emissions from Forest Degradation (DG), caused by downward shift of a forest stratum from a higher carbon stock strata to another forest stratum with lower carbon stock<sup>6</sup>;
- Removals from Forest Enhancement (Restoration) (RS), caused by upward shift of a forest land stratum with lower carbon stock to another forest/land stratum with higher carbon stock; and
- Removals from Forest Enhancement (Reforestation) (RF), caused by gain of forest carbon stock due to conversion of non-forest land stratum to a forest land stratum.

In addition, there are two (2) stable types of land/forest classes which do not impact emissions or removals, which are:

- Stable Forest (SF), where there is no change in the forest stratum; and.
- Stable Non-Forest (SNF), where there is no change in the non-forest land stratum.

-

<sup>&</sup>lt;sup>4</sup> In Lao PDR's carbon accounting, all the emissions from deforestation and forest degradation are regarded as anthropogenic, for the reasons that, the forest area is home to many different mountain ethnic minorities groups in and interacting with the forests in their daily lives; and large-scale natural disasters in forest areas or forest diseases are not common. In addition there is no suitable technology yet to clearly distinguish anthropogenic and non-anthropogenic emissions.

<sup>&</sup>lt;sup>5</sup> In the future, Lao may include restoration from improved Regenerating Vegetation management and forests remaining in the same category with increased carbon stock in this category – but for now, this is not possible due to lack of datasets. For the same reason, emissions from degradation occurring in forests remaining in the same category is also not accounted, except for the emission from selective logging estimated through measurement of tree stumps as a proxy indicator.

<sup>&</sup>lt;sup>6</sup> In addition to the use of land/forest cover change data from Forest Type Maps, impact of logging is estimated through field survey of tree stumps. This captures degradation not only caused by downward shift of a forest stratum, but also those in same forest land stratum. Possible double-counting of emissions from degradation arising from the use of two different methods are avoided in the accounting.

Accordingly the AD will be derived as amount of changes in forest areas which relate to any of the four (4) sources and sinks as shown in following Figure 11. The four (4) sources and sinks and the two (2) stable land/forest classes serve as stratification for collecting reference data to apply design based area estimation of AD (see Section 2.4).

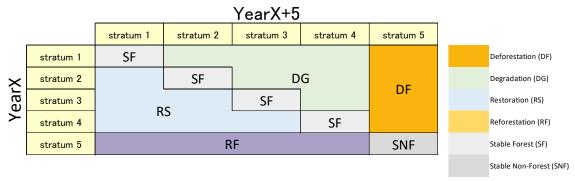


Figure 11: Sources and sinks associated with REDD + activities

#### Sources and sinks maps

The maps which shows the sources and sinks associated with REDD+ activities for 2005-2010 and 2010-201 are shown in Figure 12 and Figure 13.

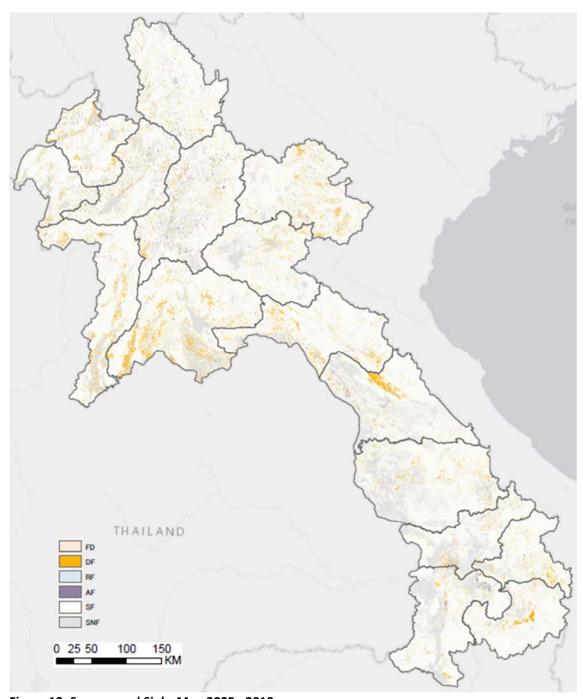


Figure 12: Sources and Sinks Map 2005 - 2010

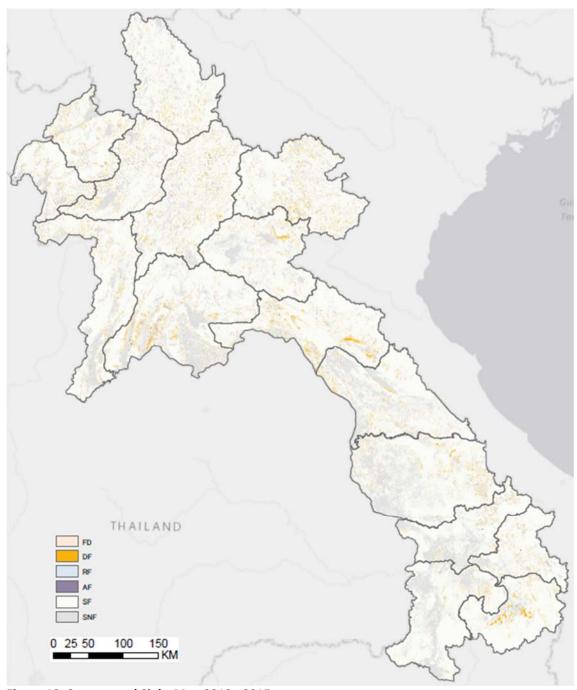


Figure 13: Sources and Sinks Map 2010 - 2015

#### 2.6 Design-based area estimation of Activity Data

The following sections explain the methods used for conducting design based area estimation using the stratified Forest Type Maps for collecting reference data.

Lao PDR decided to apply design-based area estimation with respect to generating statistically reliable estimates of AD. This method follows good practice recommended by Olofsson et al. (2014)<sup>7</sup>,

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<sup>&</sup>lt;sup>7</sup> Application of this method for the development of AD was also advised by the World Bank mission during the preparation of the Emission Reduction Program Document for the FCPF Carbon Fund.

which regards the stratified Forest Type Maps to serve as an initial stratification of the population of interest for the purposes of designing and collecting reference data which is then used to re-estimate the actual changed areas.

#### 2.6.1 Sampling design

$$n = \frac{(\sum W_i S_i)^2}{[S(\widehat{O})]^2 + (1/N)\sum W_i S_i^2} \approx \left(\frac{\sum W_i S_i}{S(\widehat{O})}\right)^2$$

Where

N = number of sample points for the stratum of interest

 $S(\overline{O})$  = standard error of the estimated overall accuracy that we would like to achieve

Wi = mapped proportion of area of stratum i,

Si = standard deviation of stratum i.

The sample size was determined by using the formula by Cochran (1977), assuming that the sampling cost of each stratum is the same. The calculation was done using FAO SEPAL which allows automated calculation of sampling size and distribution. The following values were set as the target for allocating statistically sound sampling size<sup>8</sup>:

- Standard error of 0.01 for the overall user accuracy;
- Standard error of 0.7 for Forest Degradation, Deforestation, Restoration and Reforestation;
- Standard error of 0.9 for Stable forest and Stable Non-Forest; and
- Minimum sample size for each stratum is 30.

As a result, the sampling design for the reference data was created as shown in Table 12 and Table 13.

The actual sample size for the period 2005-2010 are shown in Table 12. The total number of plots sampled was 956 plots, where 30 sampling plots were given to DG, DF, RF and RS respectively, to ensure statistical soundness (i.e. otherwise, from proportional allocation, the sample size would be too few). The total number sampled for SF and SNF were 730 plots and 106 plots respectively.

Table 12: Sampling design per source/sink 2005 - 2010

Souce/Sink Category	Degradation	Deforestation	Restoration	Reforestation	Stable forest	Stable non- forest	Total
Area (ha)	242,891	719,348	85,895	277,082	18,986,780	2,742,262	23,054,258
Expected User's Accuracy	0.70	0.70	0.70	0.70	0.90	0.90	
Wi (Mapped proportion)	0.01	0.03	0.00	0.01	0.82	0.12	
Si (Standard Deviation)	0.46	0.46	0.46	0.46	0.30	0.30	
Wi*Si	0.00	0.01	0.00	0.01	0.25	0.04	0.31

-

 $<sup>^{8}</sup>$  According to Congalton and Green (2008), the minimum sample size for assessing the accuracy of remotely sensed data is recommended to be in the range of 20 - 100 samples.

$S(\widehat{P})$ (SE overall accuracy)	0.01
$\left(\frac{\sum W_i S_i}{S(\hat{P})}\right)^2$	955.41
Total Number of Samples	956

		Total					
equal	159.33	159.33	159.33	159.33	159.33	159.33	956
Proportional	10	30	4	11	787	114	956
Adjusted	30	30 30 30 30 730 106					

Similarly, for the period 2010-2015, as shown in Table 13, the total number of plots sampled was 942 plots, where 30 sampling plots were given to DG, DF, RF and RS respectively, and the total number sampled for SF and SNF were 703 plots and 119 plots respectively.

Table 13: Sampling design per source/sink 2010 - 2015

Souce/Sink Category	Degradation	Deforestation	Restoration	Reforestation	Stable forest	Stable non- forest	Total
Area (ha)	297,003	320,381	107,382	259,621	18,867,882	3,201,989	23,054,258
Expected User's Accuracy	0.70	0.70	0.70	0.70	0.90	0.90	
Wi (Mapped proportion)	0.01	0.01	0.00	0.01	0.82	0.14	
Si (Standard Deviation)	0.46	0.46	0.46	0.46	0.30	0.30	
Wi*Si	0.01	0.01	0.00	0.01	0.25	0.04	0.31

$S(\widehat{P})$ (SE overall accuracy)	0.01
$\left(\frac{\sum W_i S_i}{S(\hat{P})}\right)^2$	941.00
Total Number of Samples	942

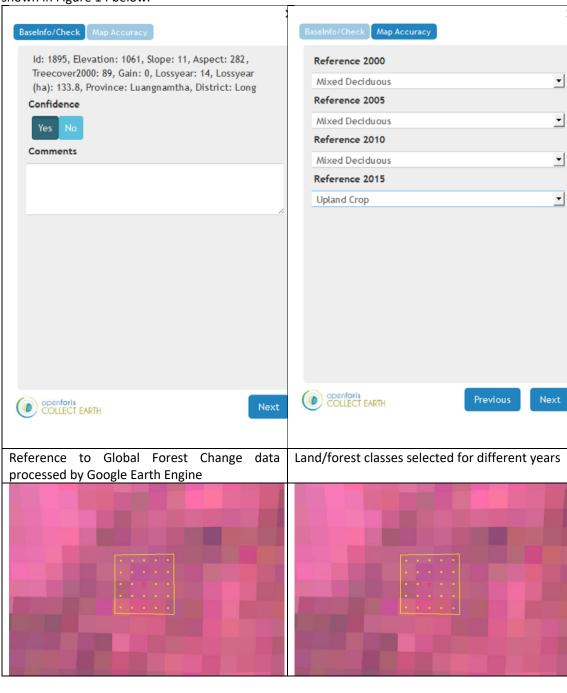
	Sample size per stratum							
Equal	157.00	157.00	157.00	157.00	157.00	157.00	942	
Proportional	12.14	13.09	4.39	10.61	770.94	130.83	942	
Adjusted	30	30	30	30	703	119	942	

#### 2.6.2 Response design

The response design provides the best available interpretation of change for each spatial unit sampled. The spatial assessment unit was set as 1 ha ( $100 \times 100 \text{ m}$ ), and square plots laid out with an internal grid and 5 x 5 = 25 reference points (to guide the interpretation) were prepared. The square plots were visually (manually) interpreted using high and medium resolution satellite imagery as the reference data.

High and medium resolution satellite imagery were obtained from repositories accessible through Google Earth and Google Earth Engine, as well as the satellite WMS layers (Landsat2000, SPOT 2005, RapidEye 2010, and RapidEye 2015) of FIPD and already made available for use through the Collect Earth tool<sup>9</sup>. Protocols and rules, such as reference labelling, were agreed on before conducting the assessment.

Some examples from the customized interface of Collect Earth for the reference data design are shown in Figure 14 below.



<sup>&</sup>lt;sup>9</sup> www.openforis.org/

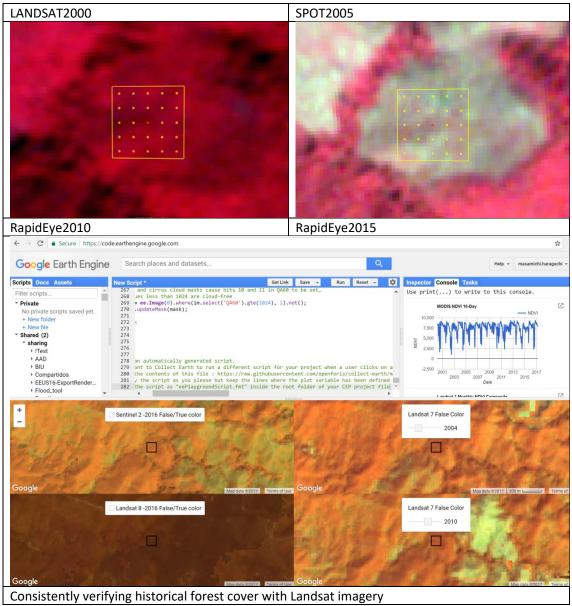


Figure 14: Example of reference data design using Collect Earth

#### 2.6.3 Creation of error matrix

After the sampling design was determined, the sampling plots were interpreted and the resulting reference data were summarized into the error matrix as shown in Table 14 for the period 2005-2010 and Table 15 for the period 2010-2015 respectively.

Table 14: Error matrix per source/sink 2005 - 2010

		Reference data							
	DF	DG	RF	RS	SF	SNF	Total		
DF	22	3	1	0	2	2	30		
DG	1	19	2	0	8	0	30		
RF	0	0	21	0	2	7	30		
RS	1	0	1	25	2	1	30		
SF	2	5	5	11	686	21	730		
SNF	1	2	0	2	8	93	106		
Total	27	29	30	38	708	124	956		

Table 15: Error matrix per source/sink 2010 - 2015

		Reference data							
	DF	DG	RF	RS	SF	SNF	Total		
DF	25	1	1	0	2	1	30		
DG	1	19	2	0	8	0	30		
RF	1	0	18	0	3	8	30		
RS	1	0	0	23	6	0	30		
SF	1	8	3	13	660	18	703		
SNF	2	0	5	0	18	94	119		
Total	35	27	28	36	695	121	942		

#### 2.6.4 Results of design-based estimation of Activity Data

From the error matrix, the areas for the four (4) sources and sinks (Deforestation, Degradation, Restoration, Reforestation) and the two (2) stable land/forest classes (Stable Forest, Stable Non-Forest) were calculated as shown in Table 16 and Table 17 below.

Table 16: Areas per source/sink 2005 - 2010

<u>Class</u>	DF	DG	RF	RS	SF	SNF
DF	0.0229	0.0031	0.0010	0.0000	0.0021	0.0021
DG	0.0004	0.0067	0.0007	0.0000	0.0028	0.0000
RF	0.0000	0.0000	0.0084	0.0000	0.0008	0.0028
RS	0.0001	0.0000	0.0001	0.0031	0.0002	0.0001
SF	0.0023	0.0056	0.0056	0.0124	0.7739	0.0237
SNF	0.0011	0.0022	0.0000	0.0022	0.0090	0.1044
<u>Reference Class</u> <u>Proportion</u>	0.0267	0.0177	0.0159	0.0178	0.7888	0.1331
<u>Standard error</u>	0.00324	0.00357	0.00295	0.00405	0.00808	0.00659
<u>95% CI</u>	0.00635	0.00699	0.00578	0.00793	0.01584	0.01293
Area	616,370	407,553	367,038	409,422	18,186,260	3,067,614

Table 17: Areas per source/sink 2010 - 2015

<u>Class</u>	DF	DG	RF	RS	SF	SNF
DF	0.0116	0.0005	0.0005	0.0000	0.0009	0.0005
DG	0.0021	0.0077	0.0004	0.0000	0.0026	0.0000
RF	0.0004	0.0000	0.0068	0.0000	0.0011	0.0030
RS	0.0002	0.0000	0.0000	0.0036	0.0009	0.0000
SF	0.0012	0.0093	0.0035	0.0151	0.7684	0.0210
SNF	0.0012	0.0093	0.0035	0.0151	0.7684	0.0210
<u>Reference Class</u> <u>Proportion</u>	0.0176	0.0126	0.0176	0.0056	0.8597	0.0868
<u>Standard error</u>	0.00265	0.00204	0.00252	0.00203	0.00618	0.00607
<u>95% CI</u>	0.00478	0.00688	0.00681	0.00819	0.01727	0.01413
Area	409,372	403,594	391,406	431,235	18,326,333	3,092,318

As the AD are the volume of area changed among the 5 strata, the areas above were proportionally disaggregated back to the changes among the 5 strata, and the final AD are determined as show in tables below:

**Table 18: Activity Data 2005 - 2010** 

		2010					
	ha	Stratum 1	Stratum 2	Stratum 3	Stratum 4	Stratum 5	
2005	Stratum 1	2,502,263	3,066	0	1,806	2,449	Deforestation
	Stratum 2	3,685	9,229,338	0	363,636	92,783	Degradation
	Stratum 3	0	151	1,163,630	39,045	29,008	Restoration
	Stratum 4	217	401,260	4,109	5,291,029	492,130	Reforestation
	Stratum 5	0	0	0	367,038	3,067,614	No Change
					Total	23,054,258	

Table 19: Activity Data 2005 – 2010: annual amount of change

ha/year	Stratum 1	Stratum 2	Stratum 3	Stratum 4	Stratum 5	
Stratum 1	435,401	305	0	179	476	
Stratum 2	129	1,605,932	0	36,120	18,047	
Stratum 3	0	5	202,475	3,878	5,642	
Stratum 4	8	14,030	144	920,655	95,725	
Stratum 5	0	0	0	46,180	457,044	

Deforestation
Degradation
Restoration
Reforestation
No Change

Deforestation
Degradation
Restoration
Reforestation
No Change

Table 20: Activity Data 2010 - 2015

		2015				
	ha	Stratum 1	Stratum 2	Stratum 3	Stratum 4	Stratum 5
2010	Stratum 1	2,530,772	482	17	1,186	8,215
	Stratum 2	0	9,062,250	425	380,043	142,609
	Stratum 3	0	42	1,153,689	21,440	15,516
	Stratum 4	0	430,826	367	5,579,623	243,032
	Stratum 5	0	0	0	391,406	3,092,318
					Total	23,054,258

Table 21: Activity Data 2010 – 2015: annual amount of change

ha/year	Stratum 1	Stratum 2	Stratum 3	Stratum 4	Stratum 5	
Stratum 1	651,389	89	3	218	1,607	Deforestation
Stratum 2	0	2,332,511	78	69,918	27,902	Degradation
Stratum 3	0	3	296,945	3,944	3,036	Restoration
Stratum 4	0	26,820	23	1,436,126	47,550	Reforestation
Stratum 5	0	0	0	64,905	800,497	No Change

#### 2.7 Map accuracy and uncertainty of activity data

From the error matrix (shown in Section 2.5.3), user accuracy and producer accuracy of the Forest Type Maps were estimated for the four (4) sources and sinks and the two (2) stable land/forest classes. Finally, the uncertainty of AD was estimated as show in Table 22 and Table 23 below:

Table 22: Map accuracy and uncertainty of Activity Data 2005 - 2010

<u>Class</u>	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%					

Table 23: Map accuracy and uncertainty of Activity Data 2010 - 2015

	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	,				
<u>Class</u>	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%					

#### 3. CONCLUSIONS AND AREAS FOR FUTURE IMPROVEMENT

The Forest Type Maps (wall-to-wall maps) for year 2005, 2010 and 2015 were developed through consistent method, and the forest cover change for the period 2005-2010 and 2010-2015 were assessed with spatially explicit observations of land use and land-use change. The accuracy of the resulting data was assessed and the changed areas were adjusted accordingly to develop the final AD. From this, the uncertainty of AD was estimated.

The data are made accessible to public through the NFMS Web portal <a href="http://nfms.maf.gov.la:4242/nfms/">http://nfms.maf.gov.la:4242/nfms/</a> to ensure transparency.

Three areas for future improvement are suggested to aim step-wise improvement as well as to further reduce the uncertainty of AD:

#### 1) Improvement of classification between MD and RV

The RV study, based on analysis of historical tree loss dataset from Hansen et al. combined with field surveys to study the time required for regeneration to meet the forest definition after slash and burning found seven years as the threshold year. This information was used to improve the accuracy of classification between RV and MD, which is a continuous phases of regeneration. At the same time, because of its characteristics, the data of Hansen et al. data does not detect repeated slash and burn incidents, which is a typical land-use practice in the Lao PDR. For the future forest mapping, Lao PDR will attempt to explore methods to detect repeated slash and burn practices in order to enable further analysis of land/forest cover change over time.

#### 2) Updating Forest Type Map 2015 map and Forest Type Maps

As explained in Section 2.3.2, distinguishing UC and OA was also a challenge, as they have very similar texture on satellite imagery. Therefore, in the current mapping method, if a land parcel (polygon) is interpreted as UC for more than 10 years (continuously interpreted as UC over the 2 time periods of 2005-2010 and 2010-2015) it was determined as permanent agricultural land and the classification of the latter year was revised to OA class. This is an example of challenges of conducting forest mapping with satellite imagery of a single year.

In the future, Lao PDR may explore using options, such as the technologies to analyze 'big data', multi-temporal satellite dataset available, and GIS data from different sources (e.g. land concession data), which meet its needs.

#### 3) Further capacity building of the remote sensing, GIS and IT engineers

FIPD/DOF has been increasing their remote sensing capacity with the technical and financial support from development partners and projects. However, under rapid innovation of remote sensing, GIS and IT technologies, demand for sufficient number of competent engineers/team is increasing. Particularly the skills and knowledge of the skilled senior engineers needs to systematically be passed on to the younger generation. Also, there is an emerging need for IT engineers who can manage and operate database systems which handle large and diverse range of digital data.

In order to periodically develop the AD for the MRV, continuous capacity building efforts is inevitable. Development partners can continue to play an important role on systemizing the knowhow, training on planning, development and analysis of data, and support the FIPD/DOF staff to catch-up with the innovative technologies. FIPD/DOF plans to develop a Standard Operation Procedure (SOP) for forest mapping through the 1<sup>st</sup> national MRV currently scheduled in 2019, in order to standardize the mapping techniques and to allow systematic improvement into the future.

# 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**

January 2018

Department of Forestry
Ministry of Agriculture and Forestry, Lao PDR

## **Table of Contents**

1.	Intr	oduction	1
	1.1	Objectives	. 1
	1.2	Notes on analytical considerations	. 1
2.	Dat	aset used	3
	2.1 Fo	rest biomass data from the 2nd NFI	. 3
	2.2 Bio	omass data of Regenerating Vegetation from the "RV survey"	. 5
	2.3	Allometric equations for the three major forest classes	. 8
3.	Esti	mation Methods of biomass and carbon stock	10
	3.1	Estimation of biomass by land/forest class	10
	3.1.1	Above Ground Biomass (AGB)	10
	3.1.2	Dead Wood	12
	3.1.3	Below Ground Biomass (BGB)	13
	3.2	Conversion of biomass to carbon stock	14
	3.3	Conversion of carbon stock (tC) into tCO2e	14
	3.4	Estimation of carbon stock after stratification	14
4.	Res	ult	16
	4.1	Average carbon stock	16
	4.2	Emission/Removal Factors	16
5.	Und	certainty analysis	17
	5.1	Method of uncertainty assessment	17
	5.1.1	Sources of uncertainty of Emission/Removal factors	17
	5.1.2	Assessment of uncertainty related to estimation of Emission/Removal Factors 1	18
	5.2	Uncertainty assessment of carbon stock	20
	5.3	Estimation of uncertainty after stratification	21
	5.4	Uncertainty by stratum	21
	5.5	Uncertainty of Emission/Removal Factors	21
6.	Disc	cussion	23
	6.1	Usability of the 1st NFI data	23

6	Exclusion of Deadwood from the carbon pool	24
7.	Conclusion and areas for future improvement	26
8.	eferences	27
Anr	1: Carbon Stocks per Land/Forest classes and sources of data	28
Anr	2: List of equation, root shoot ratio and carbon fraction	29
Lis	of Tables	
	able 2-1: Number of RV Survey clusters in each region/province	6
	able 2-2: Survey sites for each forest type in AE survey	8
	able 3-1: List of allometric equation for calculating tree AGB	10
	able 3-2: Average dry weight/tree of saplings by forest type	11
	able 3-3: Average carbon stock of non-timber vegetation (NTV) by forest class	11
	able 3-4: Lying deadwood densities (g/cm³) by density class and forest type	13
	able 3-5: Root-to-Shoot rations by forest type and AGB threshold	13
	able 4-1: Average carbon stock (tC/ha) of the 5 strata	16
	able 4-2: Emission/Removal Factors (tCO2e/ha)	16
	able 5-1: Cause of uncertainty and relevance for the estimation of Emission/Remova	als 17
	able 5-2: Uncertainty of AGB originating from the allometric equations	19
	able 5-3: Uncertainty of AGB originating from measurement error	19
	able 5-4: Total uncertainty assessment of carbon stock	20
	able 5-5: Uncertainty in carbon stock/ha by stratum	21
	able 5-6: Emission/Removal Factors (Uncertainty (%))	22
	able 5-7: Uncertainty of Emission/Removal Factors per source and sink	22
	able 6-1: Comparison of the 1 <sup>st</sup> and 2 <sup>nd</sup> NFIs	23
	able 6-2: Carbon stock and uncertainty by different pools	25

Table 6-3: Emission from deforestation by DW pool	25
List of Figures	
Figure 2-1: Surveyed plot by forest class in the 2 <sup>nd</sup> NFI	4
Figure 2-2: Floating cluster design	4
Figure 2-3: Nested circle plots	5
Figure 2-4: Clusters with three ranged square plots	7

#### Acronyms

AE Allometric Equation
AGB Above Ground Biomass

B Bamboo

BGB Below Ground Biomass
CF Coniferous Forest
CI Confidence Interval

DAFO District Agriculture and forest Office

DBH Diameter at Breast Height
DD Dry Dipterocarp Forest
DOF Department of Forestry

DW Dead Wood EF Emission Factor EG Evergreen Forest

E/R F Emission and Removal Factor

FIPD Forestry Inventory and Planning Division

FREL Forest Reference Emission Level

FRL Forest Reference Level

F-REDD Sustainable Forest Management and REDD+ Support Project in the LAO PDR

GIS Geographic Information System

GL Guideline

IPCC Intergovernmental Panel on Climate Change

Lao PDR Lao People's Democratic Republic

JICS Japan International Cooperation System

MAF Ministry of Agriculture and Forestry

MCB Mixed Coniferous Broadleaved Forest

MD Mixed Deciduous Forest
NFI National forest Inventory

NFIS National Forest Information System project

NTV Non-Tree Vegetation

PAFO Provincial Agriculture and Forest Office

REDD+ Reducing Emissions from Deforestation and Forest Degradation and the role of

conservation of forests and enhancement of forest carbon stock

RF Removal Factor

RV Regenerating Vegetation StD Standard Deviation StE Standard errors

UNFCCC United Nations Framework Convention on Climate Change

#### 1. Introduction

#### 1.1 Objectives

This report aims to describe the methods and the final results of the development of Emission and Removal Factors (E/R factors) used in the construction of Forest Reference Emission Level (FREL)/Forest Reference Level (FRL) for the national level to be submitted to the United Nations Framework Convention on Climate Change (UNFCCC).

The main inputs for the development of the E/R factors are:

- The 2<sup>nd</sup> National Forest Inventory (NFI) conducted between 2015 and 2017 by the Forest Inventory and Planning Division (FIPD) of the Department of Forestry (DOF) under the Ministry of Agriculture and Forestry (MAF).<sup>1</sup> The purpose of the 2<sup>nd</sup> NFI was to measure forest biomass of the five forest classes: Evergreen Forest (EG), Mixed Deciduous Forest (MD), Dry Dipterocarp Forest (DD), Coniferous Forest (CF) and Mixed Coniferous Broadleaf (MCB) (Section 2.1).
- A survey for the Regenerating Vegetation (RV) class (which was outside the scope of the 2<sup>nd</sup> NFI), conducted by FIPD to study the years for a forest fallow (classified as "regenerating vegetation": RV) to reach the forest status according to Lao's forest definition, as well as to measure the biomass of this vegetation class (Section 2.2).
- To improve the accuracy of forest biomass estimation, Lao PDR developed country-specific allometric equations for the three major forest classes: EG, MD and DD (Section 2.3). Other land/forest classes use IPCC default values or biomass data from neighboring Vietnam.

In this report, the above results were combined under the methodologies to estimate biomass, carbon stock to determine the E/R factors as presented in Chapter 3. The report also presents actual results of estimation and the final E/R factors in Chapter 4. The issues related to the use of the 1<sup>st</sup> NFI<sup>2</sup>, and accounting of Dead Wood (DW) are discussed in Chapter 5, and lastly, the conclusion and areas for future improvement are summarized in Chapter 6.

#### 1.2 Notes on analytical considerations

This report is written based on the following understandings (details are discussed in Chapter 5):

- a) Lao PDR conducted its 1st NFI in 1990s. Review of the 1<sup>st</sup> NFI data found that they are not suitable due to the limitation in data representativeness, and the gap of nearly 20 years between the 1<sup>st</sup> NFI and the 2<sup>nd</sup> NFI. Therefore, only the data from the 2<sup>nd</sup> NFI are used for the development of E/R factors.
- b) The 2<sup>nd</sup> NFI measured Dead Wood (DW) in the five forest classes (EG, MD, DD, CF, MCB). The result showed that DW are not significant source of emissions (approximately 2.3% of the total emissions in the national area). Also, the biomass survey of RV (different from the 2<sup>nd</sup> NFI) did not measure DW

<sup>&</sup>lt;sup>1</sup> The 2<sup>nd</sup> NFI was technically and financially supported by "Sustainable Forest Management and REDD+ Support Project in the Lao PDR (F-REDD)" under JICA.

<sup>&</sup>lt;sup>2</sup> Lao PDR conducted its 1<sup>st</sup> NFI in the late '90s, however, the results are decided not to be used in the development of E/R factors. See Section 5.1 for the details.

which makes the estimation inconsistent. Therefore, it was concluded not to account DW in the development of E/R factors.

#### 2. Dataset used

2.1 Forest biomass data from the 2nd NFI<sup>3</sup>

#### **Background**

Lao PDR conducted its 1<sup>st</sup> NFI in 1991-1999, covering the entire country. However, the data archiving was weak and insufficient to retroactively manipulate, in addition, methodologies applied for the 1<sup>st</sup> NFI needed improvement to make the results suitable for the use under REDD+. Improved NFI methodologies were developed through field testing in 2013 - 2015<sup>4</sup> and a manual was developed<sup>5</sup>. Then, a full NFI campaign was conducted over the two dry seasons of 2015-2016 and 2016-2017.

#### **Objectives**

The objectives of the 2<sup>nd</sup> NFI was to survey the forest biomass<sup>6</sup> of the five natural forest classes of the whole country. (Excluding forest plantations due to its relatively small area and possible use of IPCC default factors; and bamboo (B) and regenerating vegetation (RV) which do not currently meet the status as forest under the Lao forest definition <sup>7</sup>.) A standardized methodology and sample-based field measurements were applied.

#### Survey outline

#### Survey schedule

To meet Lao PDR's target to complete the national FREL/FRL by the end of 2017:

- A part of the three natural forest classes (EG, CF, MCB) were surveyed in the dry season of 2015-16 with Forest Type Map 2010 for distributing the sampling plots (as Forest Type Map 2015 was not yet completed); and
- Remaining part of EG, CF and MCB plus all MD and DD natural forest classes were surveyed in the dry season of 2016-17 with Forest Type Map 2015 for distributing the sampling plots.

A total of 559 survey plots were distributed across the five forest classes through stratified-random-sampling (see Figure 2-1). Lands classified as non-forest were not sampled. It is recognized that this may bias the resulting estimates, but the bias is not expected to be significant.

<sup>&</sup>lt;sup>3</sup> See DOF, et al. (2017). "The 2nd National Forest Inventory Survey <a href="http://dof.maf.gov.la/en/home/">http://dof.maf.gov.la/en/home/</a> for more details.

<sup>&</sup>lt;sup>4</sup> Capacity Development Project for Establishing National Forest Information System for Sustainable Forest Management and REDD (NFIS) (2013 – 2015) under JICA.

<sup>&</sup>lt;sup>5</sup> Lao PDR National Forest Inventory Standard Operating Procedures (SOP) Manual for Terrestrial Carbon Measurement.

<sup>&</sup>lt;sup>6</sup> The main target of the survey was to measure the forest biomass, however, other information, such as observed disturbances were also recorded.

<sup>&</sup>lt;sup>7</sup> Lao's forest definition includes: Minimum DBH of 10cm, minimum crown density of 20%, minimum area of 0.5ha.

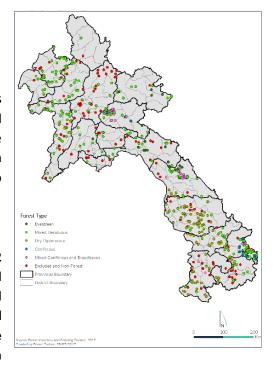
Figure 2-1: Surveyed plot by forest class in the 2<sup>nd</sup> NFI

#### Survey team

The survey teams were composed of different institutions including FIPD as the responsible agency, and Provincial Agriculture and Forest Office (PAFO), District Agriculture and Forest Office (DAFO) and villagers as the partners in each province. In total, six survey teams were formed to execute the field survey.

#### Plot design

The 'floating cluster design' as described in Figure 2-2 was used, where the first sub-plot (sub-plot A) was laid out with an anchor point placed in the plot center, and three additional sub-plots (B, C, D) were randomly placed within a 300 m radius of the anchor point, however, the sub-plot centers could not be closer than 75 m from each other nor the anchor point.



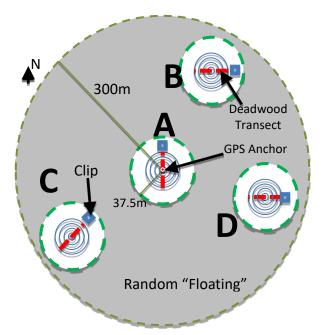


Figure 2-2: Floating cluster design

The following circular nest sizes are shown for each stratum as below. Each stratum was given different tree DBH groups to measure (See Figure 2-3).

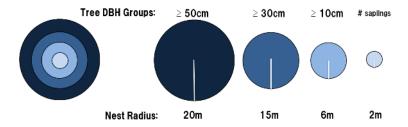


Figure 2-3: Nested circle plots

#### Carbon pools measured

AGB (standing trees, saplings, non-tree vegetation (NTV), bamboo) and Dead Wood (standing and lying deadwoods, tree stumps), were measured.

#### **Results**

Across the five forest classes surveyed, among the 559 plots distributed, a total of 420 plots were included in the estimation of forest carbon stocks. The remaining 139 plots were not included because of their land condition (contrary to the identification from the Forest Type Map, the land was actually found as non-forest in the field survey), and conflict in forest classes (the plots with 2 x forest class A and 2 x forest class B were excluded). The resulting average forest carbon stock by forest class, for the national level are shown in the Annex 1.

#### 2.2 Biomass data of Regenerating Vegetation from the "RV survey"8

#### **Background**

In Lao PDR, annually around 100,000-150,000 ha of forest lands are burned for shifting cultivation (including rotational and pioneering practices). The area is cultivated for a short period, often one year, and then left to as fallow to regenerate as "Regenerating Vegetation (RV)" which covered around 25% of the total area of Laos in 2015. Quantification of biomass from this landscape had been a challenge due to limited availability of data and allometric models<sup>9</sup>. Furthermore, distinguishing RV class from 'forest' classes through remote sensing poses a big challenge<sup>10</sup>.

<sup>&</sup>lt;sup>8</sup> See, DOF, et al. (2017). Development of a Lao-specific Equation for the Estimation of Biomass of 'Regenerating Vegetation' and Determination of the Threshold Years for its Regeneration into Forest. <a href="http://dof.maf.gov.la/en/home/">http://dof.maf.gov.la/en/home/</a> for more details.

<sup>&</sup>lt;sup>9</sup> Kiyono, et.al (2017) developed predicting models of biomass from the data of 'abandoned year' (fallowed year) and 'abandoned year average carbon stocks'. But this survey was conducted only in Luangprabang province, a northern province, thus, not suitable to represent the entire country.

<sup>&</sup>lt;sup>10</sup> Among the stages of shifting cultivation, RV and Mixed Deciduous Forest (MD) are continuous phases of regeneration in many cases, and old RV and young MD have very similar color tone and texture on satellite imagery, thus, distinguishing the two in a single satellite imagery faces technical challenges. This is in part addressed through analysis using multi-temporal remote sensing imagery.

#### **Objectives**

The objective of the 'RV Survey' was to survey the number of years of fallow required to regenerate to meet the forest definition (i.e. the threshold year), and also to survey the biomass of RV of different fallow years to estimate the average biomass.

#### Survey outline

Survey clusters were selected from the annual vegetation loss dataset of Hansen et al<sup>11</sup> to detect the year of loss on forest loss plots, then ground truthed and measured the crown cover to determine whether it had reached the forest status<sup>12</sup> or not. For each survey plot, the year of forest loss was further verified by interviewing the villagers. Only the plots confirmed as RV were measured. A total of 120 survey plots (40 survey clusters with three survey plots each) were surveyed in five provinces (Table 2-1).

Table 2-1: Number of RV Survey clusters in each region/province

Region	Province	Years after cropping	Number of Cluster	Subtotal
North	Bokeo	1,2,3,4,5,6,7,8	1 x 8	8
North	Xayabouly	1,2,3,4,5,6,7,8	1 x 8	8
North	Xiengkhouang	1,2,3,4,5,6,7,8	1 x 8	8
Central	Bolikhamxay	1,2,3,4,5,6,7,8	1 x 8	8
South	Xekong	1,2,3,4,5,6,7,8	1 x 8	8
			Total	40

Below figure shows the plot design. In each plot (10 m\*10 m square design) and DBH ( $\ge$ 5 cm) for all trees was recorded, and all other vegetation were cut at their base in the four corners of the sub-plots (size of 1m\*1m or 2m\*2m depending on the vegetation height to weigh the non-tree biomass).

Since the most common forest type for RV to regenerate into is MD forests, the tree biomass of RV was estimated by applying the allometric equation developed for MD forest class (AGB=0.407\*DBH^2.069), and the biomass of NTV (DBH < 5cm) were also estimated by using dry-wet ratio originating from the samples of the MD forest class.

Unmanned aerial vehicles (UAV) were used to take aerial photographs of the plots in order to estimate the crown cover rate, which was then used for identifying the number of years for RV to reach the forest threshold. Only the biomass from RV plots which were below 7 years of fallow was counted in the

<sup>&</sup>lt;sup>11</sup> Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850–53. Data available on-line from: <a href="http://earthenginepartners.appspot.com/science-2013-global-forest">http://earthenginepartners.appspot.com/science-2013-global-forest</a>.

<sup>&</sup>lt;sup>12</sup> Minimum DBH of 10cm, Minimum crown density of 20%, minimum area of 0.5ha.

calculation (i.e. the plots which were already beyond 7 years of fallow were regarded as MD class and not included in the calculation).

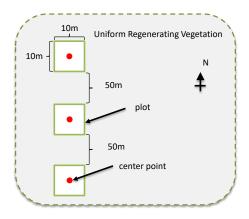


Figure 2-4: Clusters with three ranged square plots

#### **Results**

The following model using the number of years under fallow was developed.

$$AGB = 1.7573e^{0.4107Y} (R^2 = 0.7224)$$

The results of survey showed that the number of years for RV to reach the forest threshold was on average 7 years. By adding one year for cropping (classified as "UC"), it was assumed that a land slashed and burnt could potentially regenerate into forest status in 8 years if left undisturbed.

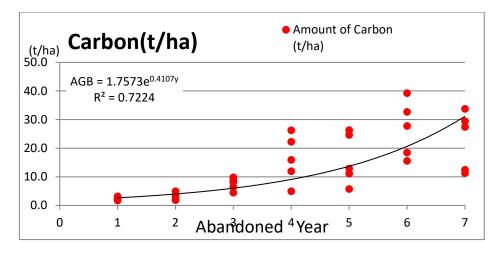


Figure 2-5: Carbon stock of plots

The total area of each age class of RV (1 year, 2 year, etc.) is not even, since different amount of lands are subject to slash and burn every year. This survey distributed an equal number of 5 clusters for each year of the RV age class without considering variations in size of age classes.

#### 2.3 Allometric equations for the three major forest classes<sup>13</sup>

#### **Background**

For REDD+, a country is requested, as feasible, to accurately estimate its forest carbon stock and changes, by using country-specific data and periodic measurement of the parameters. Development of country-specific allometric equations enable Lao PDR to improve the estimates of forest biomass in combination with the data collected through the 2<sup>nd</sup> NFI.

#### **Objectives**

To improve the accuracy of forest biomass estimation, conduct destructive measurement of trees to develop country-specific allometric equations for the three major forest classes<sup>14</sup>; Evergreen Forest (EG), Mixed Deciduous Forest (MD) and Dry Dipterocarp Forest (DD).

#### **Survey outline**

The allometric equations were developed by taking a total of 36 sample trees from each forest class (i.e. EG, MD and DD) with a variety of DBH and regional balance (See Table 2-2). Deadwood and saplings were also sampled.

All destructive field and laboratory sampling methods for trees, deadwood and saplings are based on Winrock International's standard operating procedures (Walker et al. 2014) and the FIPD/DOF survey teams were trained on the survey methods according to its procedures.

The samples were dried at 100°C using drying ovens to measure the dry weight.

Several regression models were applied to develop the allometric equations with R software.

Table 2-2: Survey sites for each forest type in AE survey

	•	• •	•		
Forest class	Province	Region	Number of	Minimum	Maximum
		-0 -	Tree	DBH(cm)	DBH(cm)
	Xayabouly	North	12		
EG	Bolikhamxay	Central	12	14.0	59.3
	Attapeu	South	12		
	Bokeo	North	12		
MD	Khammouane	Central	12	15.0	85.0
	Attapeu	South	12		
DD*	Khammouane	Central	18	16.0	67.0
DD.	Attapeu	South	18	16.0	67.0

<sup>\*</sup> DD occurrence in the Northern region is limited.

<sup>&</sup>lt;sup>13</sup>See DOF, et al. (2017). "Development of country-specific allometric equations in Lao PDR" <a href="http://dof.maf.gov.la/en/home/">http://dof.maf.gov.la/en/home/</a> for more details.

<sup>&</sup>lt;sup>14</sup> The 3 forest classes cover 66% of the total forest land of Lao PDR (EG: 13%, MD: 47%, DD: 6%) in 2015.

#### Results

The allometric equations were developed for each forest class as regression lines with a power approximation under the FAO manual (Picard et al. 2012). Among 10 possible regression lines for each forest class, one regression model was selected as below. Compared to the allometric equations developed for other forests in South-East Asia 15, the Lao-specific equations result in estimating lower biomass. Although the original data from this survey show that the highest biomass is approximately 4,300 kg, it seems reasonable and conservative to apply the equations to the obtained data that is out of DBH range.

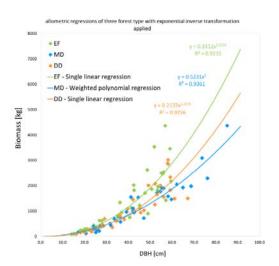


Figure 2-4: Allometric regressions of three forest types

Table 2-3: Allometric equation for three forest types

Forest	Equation	Number of	R <sup>2</sup>	AIC
Type		sample trees		
EG	$AGB = 0.3112  x  DBH^{2.2331}$	36	0.9215	18.84
MD	$AGB = 0.5231  x  DBH^2$	35	0.9081	477.24
DD	$AGB = 0.2137 \ x \ DBH^{2.2575}$	35	0.9256	10.53

<sup>...</sup> 

<sup>&</sup>lt;sup>15</sup> Allometric equations for Lao(Luang Prabang) Evergreen and Mix deciduous forest (PAREDD+,2015); Cambodia Dry Dipterocarp forest (Monda et al, 2016)

#### 3. Estimation Methods of biomass and carbon stock

The following parts explain the methodologies applied for converting the measured forest biomass into carbon stock and then to tCO2e.

#### 3.1 Estimation of biomass by land/forest class

Three carbon pools were considered for the measurement of forest biomass: Above Ground Biomass (AGB) from direct measurement and including living trees, saplings, bamboo and other non-timber vegetation (NTV); Dead Wood (DW) from direct measurement and including standing DW, stumps and lying DW; and Below Ground Biomass (BGB) using the IPCC default values.

As explained in Chapter 2, the biomass of the five forest classes were estimated from the measurement results of the 2<sup>nd</sup> NFI. Meanwhile, the biomass of RV was estimated separately using the measurement results from the RV survey. These two results are explained separately in the following sections.

#### 3.1.1 Above Ground Biomass (AGB)

#### 3.1.1.1 AGB of the five forest classes

The biomass of a plot surveyed in the 2<sup>nd</sup> NFI is calculated from the average stock of sub-plots. Then, average biomass stock for each forest class is calculated from the average stock of all plots.

#### LIVING TREES

The calculation of the biomass in kg for each tree by applying the appropriate allometric equations to the trees in different forest classes (See Table 3-1). The allometric equations for EG, MD and DD forest class were developed for Lao PDR, and the allometric equations developed in neighboring Vietnam were used for CF and MCB forests. Secondly, the biomass per tree is then converted into biomass per ha, and summed for subplots.

Table 3-1: List of allometric equation for calculating tree AGB.

C pool	Forest class	Equation	Source
AGB (living trees	EG	AGB (kg/tree) =0.3112 x DBH^2.2331	JICS (2017),
and	MD	AGB (kg/tree) =0.523081 x DBH^2	Development of specific
dead standing trees)	DD	AGB (kg/tree) =0.2137 x DBH^2.2575	allometric equations in Lao PDR.
	CF	AGB (kg/tree) =0.1277xDBH^2.3944	Hung et al (2012), Tree
	MCB	AGB (kg/tree) =0.1277xDBH^2.3944	allometric equation development for estimation of forest above-ground biomass in Viet Nam.

#### **SAPLINGS**

The saplings are defined as trees with height >1.3 m and 0 < DBH <10 cm. The biomass of saplings are estimated from the number of saplings in the first nest multiplied by the average dry weight of saplings of the same forest class (See Table 3-2). Average dry weight were measured only for the EG, MD and DD forests, and the average value of these three forest classes were used for the other two (i.e. CF, MCB).

Table 3-2: Average dry weight/tree of saplings by forest type

Forest class	Average dry weight	Source
EG	113 g	JICS (2017), Development of
DD	252 g	specific allometric equations in
MD	191 g	Lao PDR".
Others	184 g	

#### **BAMBOO**

For the measurement of biomass of bamboo poles, average diameter of five bamboo poles sampled per sub-plot was calculated and the allometric equation for bamboo developed in Vietnam was used<sup>16</sup>. Then the biomass of individual poles was multiplied by the number of poles of the clump and an expansion factor (Equation 1) to estimate the bamboo biomass per ha.

Equation 1: Allometric equation for bamboo biomass (kg) from Hung et al. (2012) 17

$$GB(kg/pole) = 0.1006 \times D^{2.222}$$

#### Where:

D = diameter of the bamboo pole (cm)

#### **NON TREE VEGETATION (NTV)**

NTV were measured in each sub-plot by establishing a small plot (50cm\*50cm). All vegetation, except for the living trees, saplings and bamboos were taken and measured for weight. Samples were brought back to the laboratory to measure the dry-wet ratio.

Table 3-3: Average carbon stock of non-timber vegetation (NTV) by forest class

Forest class	Sample size	C stock (tC/ha)	Source
EG	78	1.12	JICA(2017), 2nd
MD	358	1.09	National Forest
DD	84	0.5	Inventory Survey in Lao

<sup>&</sup>lt;sup>16</sup> Hung et al. (2012). This equation was developed by using the 120 sample trees and expected value of error (%) is 0.327.

CF	133	0.75	People's	Democratic
МСВ	764	0.57	Republic	

#### 3.1.1.2 AGB of Regenerating Vegetation (RV)

The biomass of RV, including trees, NTV, bamboo and saplings, were measured through the "RV Survey" (see Section 2.2). The estimation of carbon stock of RV, however, has a higher degree of uncertainty due to the high diversity of different vegetation species (including bamboo), topographic factors, and human factors associated to the land.

#### 3.1.2 Dead Wood

Dead Woods (DW) consists of standing trees, stumps and lying trees.

#### **STANDING DEADWOOD**

Standing DW were separated into two categories, i.e. Category 1: dead trees with twigs and branches; and Category 2: dead standing trees without branches, which was further separated into short trees and tall trees. The Category 2 trees were treated as conical cylinders, and the biomass of the Category 1 trees was calculated with respective allometric equations (See Table 3-1).

#### **STUMPS**

The biomass of stumps was calculated assuming a cylindrical shape multiplied by wood density Equation 2):

Equation 2: Equation for the estimation of stump biomass (B<sub>stump</sub> in kg) <sup>18</sup>

$$B_{stump} = \left( \left( \left( \frac{D_{mean}}{2} \right)^2 \times \pi \right) \times H_{stump} \right) \times WD \times 0.001$$

#### Where:

 $D_{mean}$  = mean diameter (cm)  $H_{stump}$  = height of the stump

 $WD = wood density (0.57 g/cm^3)$ 

#### LYING DEADWOOD

Lying DW was separated into 2 categories, i.e. hollow and solid, and the latter was further separated by three density classes (i.e. sound, intermediate, and rotten; Table 3-4). The volume of solid dead wood was calculated as a cylinder, whereas hollow dead wood was calculated as the difference between the outer cylinder and inner cylinder.

<sup>&</sup>lt;sup>18</sup> Goslee, et al (2015), P.37, equation 53.

Table 3-4: Lying deadwood densities (g/cm³) by density class and forest type

		(O, , , , , , , , , , , , , , , , , , ,		**	
Forest type	Density class	Density (g/cm³)		Source	
EG	Sound		0.39	JICS (2017), Development	
	Intermediate		0.34	of specific allometric	
	Rotten		0.26	equations in Lao PDR.	
DD	Sound		0.44		
	Intermediate		0.35		
	Rotten		0.32		
MD	Sound		0.45		
	Intermediate		0.3		
	Rotten		0.29		
Other	Sound		0.44		
	Intermediate		0.33		
	Rotten		0.3		

#### 3.1.3 Below Ground Biomass (BGB)

The BGB was estimated by using the best available Root-to-Shoot (R/S) ratios corresponding to each forest class and their average AGB.

Table 3-5: Root-to-Shoot rations by forest type and AGB threshold

Forest type	AGB threshold	Root-to- Shoot ratio (R/S ratios)	Source
EG, DD, MD, and MCB	AGB < 125t/ha	0.20	IPCC GL 2006 for National Greenhouse Gas Inventories (Chapter 4: Forest land, Table 4.4)
	AGB > 125t/ha	0.24	
CF	AGB < 50t/ha	0.46	2003 IPCC Good Practice Guidance for LULUCF
	AGB = 50 - 150t/ha	0.32	(Chapter 3: LULUCF Sector Good Practice
	AGB > 150t/ha	R/S =	Guidance, Table 3 A.1.8)
		0.23	
Plantation	AGB<50t/ha	0.46	2003 GPG(Anx_3A_1_Data_Tables3A.1.8)
	AGB=50-150t/ha	0.32	2003 GPG(Anx_3A_1_Data_Tables3A.1.8)
	AGB>150t/ha	0.23	2003 GPG(Anx_3A_1_Data_Tables3A.1.8)
Bamboo		0.82	Junpei Toriyama (http://www.ipcc- nggip.iges.or.jp/EFDB/main.php)
RV	AGB<20t/ha	0.56	IPCC GL 2006 (V4_04_Ch4_Table4.4)
	AGB>20t/ha	0.28	IPCC GL 2006 (V4_04_Ch4_Table4.4)

#### 3.2 Conversion of biomass to carbon stock

The estimated biomass was converted into carbon stock with the generic formula below:

$$Ci = TBi \times CF$$

#### Where:

TBi = total biomass of plot i (include AGB and BGB), expressed in kg.

CF = IPCC default carbon fraction value 0.46 or 0.47 depending on the land/forest class (2006 IPCC GL Volume 4, Chapter 4)

The detailed table summarizing the results is shown in the Annex 2 of this report.

#### 3.3 Conversion of carbon stock (tC) into tCO2e

The generic formula suggested in the IPCC GL 2006 below was used to convert carbon stock (tC) into tCO2e, and then the final E/R factors were determined.

$$EF \ or \ RFij \ (tCO2e/ha) = (Ci - Cj) \times 44/12$$

#### Where:

*EF or RFij* = is *EF* or *RF* when the change incurred from land use *i* to land use *j*.

Ci and Cj = is carbon stock per ha of land/forest class i and j corresponding to the changes;

44/12 is the ratio of carbon mass to CO2 mass.

If Ci > Cj, such change is considered emissions;

If Ci < Cj, such change is considered removal.

#### 3.4 Estimation of carbon stock after stratification

In order to reduce uncertainty of emissions and removals while balancing the accuracy of sampling and the cost/efforts required, the land/forest classification was collapsed into five strata as below:

- Evergreen Forest (EG) has distinctly high carbon stocks (200.0tC), thus, separated as an independent stratum Stratum 1 (expanse: 2,605,557ha, 11.3% of the total land area).
- Mix Deciduous Forest (MD), Conifer Forest (CF) and Mixed Coniferous and Broadleaved Forest (MCB) will form one stratum on the basis of similarity in carbon stocks per hectare (87.7tC, 92.6tC, 114.7tc). – Stratum 2 (expanse: 9,437,688ha, 40.9% of the total land area).
- Dry Dipterocarp Forest (DD) will form one stratum due to the difference in carbon stock from other forest classes (43.2tC), and also due to the fact that they are mostly distributed in the low-lands and prone to conversion to other land use Stratum 3 (expanse: 1,188,198ha, 5.2% of the total land area).
- Plantation (P), Bamboo (B) and Regenerating Vegetation (RV) will form one strata on the basis of similarity in average carbon stock (37.2tC, 24.4tC, 17.4tC) Stratum 4 (expanse: 6,300,445ha, 27.3% of the total land area).

• The remaining 12 non-forest classes will form one stratum – Stratum 5 (expanse: 3,522,370ha, 15.3% of the total land area).

The average carbon stock for the new strata was calculated by using weighted value as follows:

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

Where:

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

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

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

#### 4. Result

#### 4.1 Average carbon stock

The average carbon stock of the five forest classes from the 2<sup>nd</sup> NFI data are shown in Table 4-1. Only AGB and BGB were selected as the carbon pools to be accounted and DW is not accounted. The average carbon stock (and tCO2e) for the remaining land/forest classes are calculated based on the IPCC default value (IPCC GL 2006) and other available sources, except for RV which uses the results of the "RV Survey".

Table 4-1: Average carbon stock (tC/ha) of the 5 strata

Strata	tC/ha
Stratum 1 (EG)	200.0
Stratum 2 (MD/CF/MCB)	88.1
Stratum 3 (DD)	43.2
Stratum 4 (P/B/RV)	17.9
Stratum 5 (NF)	4.9

#### 4.2 Emission/Removal Factors

The E/R Factors are developed by taking the difference in average carbon stock (as tCO2e) of each forest/land strata as shown in following Table 4-2.

Table 4-2: Emission/Removal Factors (tCO2e/ha)

	Stratum 1 (EG)	Stratum 2 (MD/CF/MCB)	Stratum 3 (DD)	Stratum 4 (P/B/RV)	Stratum 5 (NF)
Stratum 1 (EG)		-410.5	-575.1	-667.6	-715.4
Stratum 2 (MD/CF/MCB)	410.5		-164.6	-257.1	-304.9
Stratum 3 (DD)	575.1	164.6		-92.6	-140.3
Stratum 4 (P/B/RV)	667.6	257.1	92.6		-47.8
Stratum 5 (NF)	715.4	304.9	140.3	47.8	

### 5. Uncertainty analysis

#### 5.1 Method of uncertainty assessment

#### 5.1.1 Sources of uncertainty of Emission/Removal factors

The IPCC GL 2006 for National Greenhouse Gas Inventories (Volume 1, Chapter 3), lists out eight broad causes of uncertainties. Some cause of uncertainty (e.g. bias) may be difficult to identify and quantify<sup>19</sup>. Accordingly, the causes of uncertainties for the E/R factors and their application in the uncertainty assessment are summarized in following Table 5-1.

Table 5-1: Cause of uncertainty and relevance for the estimation of Emission/Removals factor

Cause of Uncertainty	Relevance for the EF?	Applied (yes/no) and explanations
Lack of completeness	Considered not relevant. The 2nd NFI was complete. The survey followed the SOP.	No
Model	Relevant and significant. Affects estimation of biomass. Uncertainty in statistical models used to estimate biomass as function of tree parameters, models to estimate BGB, and models to convert from biomass to carbon.	Yes (No.2 below)
Lack of data	Relevant, but, minor. Data do not exist to estimate emissions/removals from several pools (litter and soil) which are assumed to be insignificant (< 10%).	No
Lack of representativeness of data	Partially relevant to the data of the 2 <sup>nd</sup> NFI. Emission factors come from statistically sound random sampling plots distributed across the entire country but applied to the 6 provinces. As discussed in Section 5.2, the difference is not expected to be significant.  Relevant to the RV data due to limited number of plot data.	Partially relevant to the 2 <sup>nd</sup> NFI data Yes for RV
Statistical random sampling error	Relevant and significant. Affects estimation of Emission Factors from forest inventory samples.	Yes Errors of forest carbon stock estimation are assessed (No.1 below)
Measurement error	Relevant. Measurement of tree DBH assumed to be with minor error according to the QC results, although reference data is limited	Yes (No.3 below)
Misreporting or misclassification	Considered not relevant. Field data were collected following the SOP, and the data were recorded through the tablet-based survey application to eliminate data loss and reduce data	No

<sup>&</sup>lt;sup>19</sup> Rypdal and Winiwarter, 2001

	input errors. Field survey teams were well trained before conducting survey.	
Missing data	Considered not relevant. Sampling and forest cover mapping covers 100% of the area of interest. Field data were collected following the SOP, and data were recorded through the tablet-based survey application to eliminate data loss and reduce data input errors.	No

#### 5.1.2 Assessment of uncertainty related to estimation of Emission/Removal Factors

From the analysis described, the main causes of uncertainty of E/R factors are considered as follows:

- 1. Uncertainty of AGB originating from sampling error (2<sup>nd</sup> NFI data)
- 2. Uncertainty of AGB originating from biomass equation (See Allometric Equation development report)
- 3. Uncertainty of Root-to-Shoot ratios due to the use of IPCC default values (IPCC GL 2006)
- 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 2<sup>nd</sup> NFI)

#### Estimation method for uncertainty of AGB originating from sampling error

First, estimate the mean Standard Deviation (StD) and 95% Confidential Interval (CI) of the measured carbon stock of all inventory plots for each forest class. Then, divide the CI (95%) by mean AGB (t/ha) to derive the level of uncertainty of each AGB caused by sampling error<sup>20</sup>.

#### Estimation of uncertainty of AGB originating from biomass equation

The following generic formula was used to estimate the uncertainty of the allometric equations developed for Lao PDR for the three forest classes (i.e. EG, MD and DD).

Equation 5-1
$$StD = \frac{100}{N} \sum_{i=1}^{n} \frac{|\widehat{Y}i - Yi|}{Yi}$$

$$StE = \frac{StD}{\sqrt{N}}$$

Where:

N = number of sample trees

 $\hat{Y}i$  and Yi = the predicted and measured AGB of the tree.

StD = Standard Deviation.

StE = Standard Error.

<sup>20</sup> Goslee, et al (2015), page 4, equation 5

The following Table 5-2 shows the results of assessment.

Table 5-2: Uncertainty of AGB originating from the allometric equations

Forest class	Sample size	StD	CI (95%)	StE
EG	36	23.6	7.7	3.9
MD	35	22.8	7.4	3.8
DD	35	21.7	7.1	3.6

CI: Confidence Interval

#### Uncertainty of AGB originating from measurement error

For estimating the uncertainty of AGB originating from measurement error, Standard errors (StE) were calculated based on the standard deviations (StD) and number of sample trees by using the equation 5-1 above. The same allometric equation was used to estimate the biomass measured through QC Survey, and the following table shows the result of AGB measurement error based on the QC Survey. Note that the QC survey was not able to re-measure sufficient number of EG and CF plots (e.g. QC teams unable to find the exact QC plots).

Table 5-3: Uncertainty of AGB originating from measurement error

	Number of QC survey plot	Average difference between primary plot and QA plot	StD	StE
EG	0	N/A	N/A	N/A
MD	14	9.5	11.7	3.1
DD	11	6.6	13.5	4.1
CF	0	N/A	N/A	N/A
МСВ	3	7.9	15.1	8.7

#### 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<sub>total</sub> = 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<sub>i</sub> = the percentage uncertainties associated with each of the quantities.

# $E \mbox{Quation 3.2} \\ \mbox{Combining uncertainties} - \mbox{Approach 1} - \mbox{addition and subtraction} \\$

$$U_{total} = \frac{\sqrt{\left(U_{1} \, \bullet \, x_{1}\right)^{2} \, + \left(U_{2} \, \bullet \, x_{2}\right)^{2} \, + \ldots + \left(U_{n} \, \bullet \, x_{n}\right)^{2}}}{\left|x_{1} + x_{2} + \ldots + x_{n}\right|}$$

Where:

U<sub>total</sub> = 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.

In addition, there are potential systematic uncertainties listed below which are contained in the approach applied, however, their impact on uncertainty are difficult to be assessed nor to be reduced immediately in practical manners, therefore, considered as an issue for future improvement:

- Unknown age class and growth rates of forests, influencing both removals and emission estimates; and
- Application of strata-specific E/R factors which do not explicitly estimate the emissions and removals based on their true dynamics. The resulting over-estimation of emissions from deforestation and degradation is addressed through the analysis of time-series (Section 4.3.1 of the submission) to the extent possible.

#### 5.2 Uncertainty assessment of carbon stock

The following table shows the total uncertainty of carbon stock for each forest class estimated through the propagation of error approach.

Table 5-4: Total uncertainty assessment of carbon stock

Forest class		Sources of uncertainty					
1010000000	1.	2.	3.	4.	5.	(AGB+BGB) (%)	
EG	14.0	3.9	11.5	2.7	-	18.7%	
MD	5.0	3.8	11.5	2.7	3.1	13.7%	
CF	13.2	18.0	20.3	2.7	-	30.3%	
МСВ	22.3	18.0	11.5	2.7	8.7	32.2%	
DD	8.7	3.6	11.5	2.7	4.1	15.6%	
Р	-	18.0	20.3	2.7	-	27.3%	
В	15.5	0.3	-	2.7	-	15.7%	
RV	27.0	-	0.9	2.7	-	27.1%	
NF	N/A	N/A	N/A	N/A	N/A	20.0%	

1. Uncertainty of AGB originating from sampling error

- 2. Uncertainty of AGB originating from biomass equation
- 3. Uncertainty of Root-to-Shoot ratios due to the use of IPCC default values
- 4. Uncertainty of Carbon Fraction factor due to the use of IPCC default values
- 5. Uncertainty of AGB originating from measurement error

#### 5.3 Estimation of uncertainty after stratification

In order to reduce uncertainty of emissions and removals while balancing the accuracy of sampling and the cost/efforts required, the land/forest classification explained in Section 2.2 was collapsed into five strata.

The uncertainty of average carbon stock for the new strata was calculated by using weighted value as follows:

$$Ustrata(\%) = (U1 * A1 + U2 * A2 + .... + Un * An)/(A1 + A2 + .... + An)$$

#### Where:

Ustrata = uncertainty (%) of strata calculated from uncertainty of respective land/forest class and carbon stock;

Ui = uncertainty of land/forest class (%);

Ai = total cabon stock (tC/ha) of each land/forest class in 2015.

#### 5.4 Uncertainty by stratum

As explained in Section 3.4, as the land/forest classification was stratified into five strata, the uncertainty for each stratum was calculated by using weighted value based on the area proportion. The following table shows the uncertainty for each stratum.

Table 5-5: Uncertainty in carbon stock/ha by stratum

Strata	Mean (tCO₂e/ha)	Uncertainty range (tCO₂e/ha)	Uncertainty (%)
1	733.4	+/- 137.0	18.7%
2	322.9	+/- 40.1	13.3%
3	158.3	+/- 24.7	15.6%
4	65.8	+/- 16.7	25.4%
5	18.0	+/- 3.6	20.0%

#### 5.5 Uncertainty of Emission/Removal Factors

The uncertainty of the E/R factors was calculated using abovementioned Equation 3.2 and the result is shown in Table 5-6 below.

Table 5-6: Emission/Removal Factors (Uncertainty (%))

	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%	

From above Table 5-6, uncertainty of E/R factors per source and sink are estimated as below.

Table 5-7: Uncertainty of Emission/Removal Factors per source and sink

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

#### 6. Discussion

#### 6.1 Usability of the 1st NFI data

The 1<sup>st</sup> NFI conducted in 1991-1999 measured the forest biomass of the entire country, however, applying a different methodology from the 2<sup>nd</sup> NFI. Table 6-1 shows the comparison of survey contents and design between the 1st and 2nd NFIs. Some surveyed items are comparable, however, many others are not, and some of the results from the 1st NFI are not sufficient against the requirements under REDD+.

The major shortcoming of the 1<sup>st</sup> NFI is that the survey plots were selected only from easily accessible area, thus have significant problems in data representativeness. Also, there is a gap of nearly 20 years between the 1<sup>st</sup> NFI and the 2<sup>nd</sup> NFIs, and the forests of Lao PDR have experienced significant changes during this period.

For the reasons above, Lao PDR considered that the 1<sup>st</sup> NFI shall not be used in the construction of both, the national FREL/FRL.

Table 6-1: Comparison of the 1st and 2nd NFIs

	1 <sup>st</sup> NFI	2 <sup>nd</sup> NFI		
Main Objectives	<ul> <li>Estimate growing stock</li> <li>Development of volume functions</li> <li>Use for reviewing the forest definition</li> </ul>	- Estimate forest biomass/carbon stock		
Target area	Nation wide (Only easily accessible areas, random sampling)	Nation wide (areas of five natural forest classes covering 13,231,443ha (57.4% of the national land area), random sampling)		
Implementation Year	1991-1999	2016-2017		
Number of plots	Forest: 2,368 plots	Forest: 420 plots		
Survey class	6 natural forest, 4 potential forests and others	5 natural forests		
Plot design, shape, location,	etc.			
Single plots				
Cluster plots	X	X		
Rectangular plots	X			
Circular plots		X		
Forest classification	X	X		
Location information (Latitude/longitude coordinates)	Province name only	X		
Photographs of the plots		X		
Living trees	X	X		
DBH	X	X		

Diameters at middle and		
top of bole	X	
Tree height	X	
Tree quality	X	
Population of saplings	X	X
Canopy density	X	
Non-forest class	X	X
Forest structure	X	
Species (local name)	X	X
Species (Scientific name)		X
Slope	X	X
Stumps	X	X
Diameter	X	X
Height	X	X
Non-tree vegetation		X
Fresh mass		X
Dry mass		X
Standing dead trees		X
DBH		X
Height		X
Lying Dead Wood		X
Diameter		X
Density		X
Decomposition class		X
Litter		
Fresh mass		
Dry mass		
Soil	X	
Soil type	X	
Bulk density		
Organic carbon content		
NTFP	X	X
Rattan	X	
Bamboo	X	X

#### 6.2 Exclusion of Deadwood from the carbon pool

The 2nd NFI included measurement of DW. As shown in Table 6-3, historical results showed that emissions from DW through deforestation accounts for only 2.3% of the sum of the AGB, BGB, and DW, therefore, considered insignificant. It should also be noted that the uncertainty of DW was relatively high.

Table 6-2: Carbon stock and uncertainty by different pools

AGB+BGB			DW	DW/(AG+BG+DW)		
	Average Average		Uncertainty	Ratio		
	(tC/ha)	(tC/ha)	(95%)	(%)		
EG	200.0	10.4	28.5	4.9		
MD	87.7	6.4	21.7	6.8		
DD	43.2	2.4	20.5	5.3		
CF	92.6	3.0	64.3	3.1		
MCB	114.7	9.0	49.8	7.3		

Table 6-3: Emission from deforestation by DW pool

AG+BG		DW	DW/	
MtCO2/year		MtCO2/year	(AG+BG+DW)	
National	25.02	0.59	2.3%	

Emission from DW pool shown in Table 6-3 does not include emission from forest degradation for the reason that main source of emission from forest degradation is caused by conversion of forest to RV. Nevertheless, there is no measurement data of DW in RV (therefore, not accounted). There is a concern that inclusion of DW in forest degradation may result in inconsistent estimation and causing possibility of overestimation. Therefore, DW is determined not to be included in the current estimation of E/R factors.

#### 7. Conclusion and areas for future improvement

This report presented the E/R Factor estimated by the  $2^{nd}$  NFI data, RV survey and allometric equations including country-specific ones for Lao PDR. The potential use of a) data from the  $1^{st}$  NFI and c) inclusion of DW as a carbon pool were considered.

As a result, from the perspective of data representativeness of the  $1^{st}$  NFI and the time gap between the  $1^{st}$  and the  $2^{nd}$  NFI, Lao PDR considers that the  $1^{st}$  NFI data should not be used for constructing E/R factors. Emissions from DW have historically been recorded to be insignificant and therefore omitted.

Potential improvements in future E/R factor as below.

• Secure sufficient number of survey plots per forest and non-forest classes
In the 2nd NFI, there was low congruence between the predicted and actual classification of forest
classes for the NFI plots. This resulted in lower than desired samples for non-MD forest classes. As
such, for the future iteration of the NFI, it is recommended to increase the number of non-MD plots,
to ensure minimum thresholds are met for all forest classes. Also, since the lands other than those
categorized as currently stocked (i.e. EG, MD, DD, CF, MCB, P) in the forest type maps were not
sampled, there is a concern of bias (although not significant). Thus, future NFIs should sample whole
landscapes and verify forest as well as non-forest.

#### Carbon stock of RV

The carbon stock of Regenerating Vegetation (RV) was calculated from the average carbon stock of each year. Since this survey distributed five clusters for each year of fallow, variations in the area of RV for each year are not considered. Therefore, there is a limitation in the representativeness of data and resulting uncertainty was relatively high. For future NFIs, the number of years after abandonment is suggested to include as survey item with support from remote sensing. The future survey of the carbon stock of RV should also consider including measurement of DW.

#### • Continuous improvement of E/R factors

Default value from the IPCC GLs were used to estimate carbon stock for some of the land/forest classes where country-specific data do not exist. These are potential areas for improvement in order to reduce the uncertainty of E/R factors. As allometric equations for minor forest classes used ones from neighboring country (i.e. Vietnam), developing country-specific allometric equation for minor forest classes shall contribute to reducing the uncertainty. Also, as Lao PDR considers to account non-CO2gas from field burning, developing a country-specific biomass combustion factor which can be applied for slash and burn activities shall be considered

#### 8. References

- JICA (2014). Validation and Registration of the Project on REDD plus through Participatory Land and Forest Management for Avoiding Deforestation in Lao PDR(Technical Cooperation Report)
- JICA (2015). Completion Report Annex 8, Outline of 1<sup>st</sup> NFI for The Capacity Development Project for Establishing National Forest Information System for Sustainable Forest Management and REDD+ (Phase I)
- JICA (2016). Completion Report for The Capacity Development Project for Establishing National Forest Information System for Sustainable Forest Management and REDD+(Phase II)
- DOF, JICA (2017). The 2nd National Forest Inventory Survey <a href="http://dof.maf.gov.la/en/home/">http://dof.maf.gov.la/en/home/</a>
- DOF, JICA (2017). Development of a Lao-specific Equation for the Estimation of Biomass of 'Regenerating Vegetation' and Determination of the Threshold Years for its Regeneration into Forest. <a href="http://dof.maf.gov.la/en/home/">http://dof.maf.gov.la/en/home/</a>>
- DOF, JICS (2017). Development of country-specific allometric equations in Lao PDR" <a href="http://dof.maf.gov.la/en/home/">http://dof.maf.gov.la/en/home/</a>
- Katherine Goslee, Sarah M Walker, Alex Grais, Lara Murray, Felipe Casarim, and Sandra Brown (2015): Module C-CS: Calculations for Estimating Carbon Stocks, LEAF REDD+ Technical Guidance Series.
- Kiyono et al (2007). Predicting Chrono sequential changes in carbon stocks of pachymorph bamboo communities in slash-and-burn agricultural fallow, northern Lao People's Democratic Republic
- Rypdal and Winiwarter (2001). Assessing the uncertainty associated with national greenhouse gas emission inventories: a case study for Austria. *Atmospheric Environment*.

Annex 1: Carbon Stocks per Land/Forest classes and sources of data

IPCC definitions	Level 1	Level 2	tC/ha	tCO2/ha	Data source	
4011110115	Current	Evergreen Forest	200.0	733.4	2nd NFI_Lao original AE	
		Mixed Deciduous Forest	87.7	321.5	2nd NFI_Lao original AE	
		Dry Dipterocarp Forest	43.2	158.3	2nd NFI_Lao original AE	
Forest	Forest	Coniferous Forest	92.6	339.6	2nd NFI_Vietnam AE	
Land		Mixed Coniferous and Broadleaved Forest	114.7	420.7	2nd NFI_Vietnam AE	
		Forest Plantation	37.2	136.5	GPG GL(2003) Anx_3A_1_Data_Tables(Other species)	
	Potential Forest	Bamboo	24.4	89.5	Vietnam modified REL report	
		Regenerating Vegetation	17.4	63.8	RV survey	
	Other Vegetated Areas	Savannah	16.4	60.0	IPCC EF DB 513130	
Grassland		Scrub	38.6	141.7	2006 IPCC guideline V4 Chp4 Table4.7	
		Grassland	7.4	27.2	LULUCF Sector Good Practice Guidance P3.109 Table3.4.2	
Wetland	Aleas	Swamp	0	0	No default value	
	Cropland	Upland Crop	5.0	18.3	LULUCF Sector Good Practice Guidance P3.88 Table3.3.8 (Annual)	
		Rice Paddy	5.0	18.3	LULUCF Sector Good Practice Guidance P3.88 Table3.3.8 (Annual)	
Cropland		Other Agriculture	2.6	9.5	LULUCF Sector Good Practice Guidance P3.88 Table3.3.8 (Perenial)	
		Agriculture Plantation	38.8	142.3	IPCC EF DB 511318 other species	
Settlements/ Other land /Wetlands	Non Vegetated Areas	Non Vegetated Areas/Other/Water	-	-	-	

## Annex 2: List of equation, root shoot ratio and carbon fraction

		AGB			AGB→BGB		Biomass→Carbon	
Level 1	Level 2	Allometric Equation	Data source	Condition	Conversion Factor	Data source	Conversion Factor	Data source
	Evergreen Forest	AGB=0.3112 x DBHY2.2331	JICS Forest Preservation	AGB<125t/ha	0.20	2006 GL(V4_04_Ch4_Table4.4)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
			Programme TA6 Final report	AGB>125t/ha	0.24	2006 GL(V4_04_Ch4_Table4.4)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
	Mixed Deciduous Forest	AGB=0.523081 x DBH <sup>2</sup> 2	JICS Forest Preservation	AGB<125t/ha	0.20	2006 GL(V4_04_Ch4_Table4.4)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
		705=0.020001 X 5511 2	Programme TA6 Final report	AGB>125t/ha	0.24	2006 GL(V4_04_Ch4_Table4.4)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
	Dry Dipterocarp Forest	AGB=0.2137 x DBH^2.2575	JICS Forest Preservation	AGB<125t/ha	0.20	2006 GL(V4_04_Ch4_Table4.4)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
		7.65=0.2.101 X 5511 2.2010	Programme TA6 Final report	AGB>125t/ha	0.24	2006 GL(V4_04_Ch4_Table4.4)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
Current	Coniferous Forest		UN-REDD	AGB<50t/ha	0.46	2003 GPG(Anx_3A_1_Data_Tables3A.1.8)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
Forest		AGB=0.1277xDBH^2.3944	Programme, Hanoi, Viet Nam(2012).	AGB=50-150t/ha	0.32	2003 GPG(Anx_3A_1_Data_Tables3A.1.8)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
			Viot Flam(2012).	AGB>150t/ha	0.23	2003 GPG(Anx_3A_1_Data_Tables3A.1.8)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
	Mixed Coniferous and Broadleaved Forest	AGB=0.1277xDBH*2.3944	UN-REDD Programme, Hanoi,	AGB<125t/ha	0.20	2006 GL(V4_04_Ch4_Table4.4)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
		765-0.1217855112.0344	Viet Nam(2012).	AGB>125t/ha	0.24	2006 GL(V4_04_Ch4_Table4.4)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
	Forest Plantation  Use IPCC default value			AGB<50t/ha	0.46	2003 GPG(Anx_3A_1_Data_Tables3A.1.8)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
		Use IPCC default value	IPCC EF DB 511220 Broad leaf)	AGB=50-150t/ha	0.32	2003 GPG(Anx_3A_1_Data_Tables3A.1.8)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
				AGB>150t/ha	0.23	2003 GPG(Anx_3A_1_Data_Tables3A.1.8)	0.47	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
	Bamboo		><	0.82	Junpei Toriyama(http://www.ipcc- nggip.iges.or.jp/EFDB/main.php)	0.46	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land	
Potential Forest	Regenerating Vegetation Where	AGB = 1.7573e0.4107Y	FPP TA6 Final report	AGB<20t/ha	0.56	2006 GL(V4_04_Ch4_Table4.4)	0.46	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
		Where: Y is abandoned years after cropland		AGB>20t/ha	0.28	2006 GL(V4_04_Ch4_Table4.4)	0.46	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
	Savannah			><	0.50	GPG(Chp3_4_Grassland_Table3.4.3)	0.46	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
Other Vegetated	Scrub			$\geq \leq$	2.80	GPG(Chp3_4_Grassland_Table3.4.3)	0.46	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
Areas	Grassland			$\geq <$	1.60	GPG(Chp3_4_Grassland_Table3.4.3)	0.46	2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land
	Swamp							
	Upland Crop			According to GPG In the IPCC Guide		63, or incorporation of crop residues, the		
	Rice Paddy		contribution from root biomass from the harvested crop is not accounted for. Ideally, both the aboveground and the root biomass should be accounted for to					
Cropland	Other Agriculture		include nitrogen from the total plant, but the root biomass cannot readily be estimated.					
Cropianu	Agriculture Plantation			AGB<50t/ha	0.46	2003 GPG(Anx_3A_1_Data_Tables3A.1.8)		
				AGB=50-150t/ha	0.32	2003 GPG(Anx_3A_1_Data_Tables3A.1.8)		
				AGB>150t/ha	0.23	2003 GPG(Anx_3A_1_Data_Tables3A.1.8)		