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Annex 14: Emissions Factor Report

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Abbreviations

AD	Activity data
AE	Allometric Equation
AGB	Above Ground Biomass
BCEF	Biomass Conversion and Expansion Factors
BEF	Biomass Expansion Factor
BGB	Below Ground Biomass
BUR	Biannual Updated Report
CF	Carbon Fraction
DBH	Diameter at Breast Height
EF	Emission Factor
EBF-R	Evergreen Broadleaf Forests, Rich
EBF-M	Evergreen Broadleaf Forests, Medium
EBF-P	Evergreen Broadleaf Forests, Poor
FAO	Food and Agriculture Organization
FIPI	Forest Inventory and Planning Institute
GHG	Green House Gases
IPCC	Intergovernmental Panel on Climate Change
JICA	Japan International Cooperation Agency
LULUCF	Land use, Land Use Change and Forestry
MARD	Ministry of Agriculture and Rural Development
MONRE	Ministry of Natural Resources and Environment
Mha	Millions hectare
NCC	North Central Coast
NFIMAP	National Forest Inventory, Monitoring and Assessment Program
PSU	Primary Sample Unit
REDD+	Reducing Emission from Deforestation, forest Degradation, forest carbon conservation and enhancement and sustainable management of forests
RF	Removal Factors
SD	Standard Deviation
SCC	South Central Coastal
SE	Standard Error
SSP	Secondary Sample Plot
STDEV	Standard Deviation
tC	Tonne of carbon
UNFCCC	United Nation Framework in Climate Change
WD	Wood Density

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1 INTRODUCTION

This report is prepared under the FCPF to support the develop of a reference level for the north central coast (NCC) as a part of the proposal for the Emission Reduction Program (ER-P). The aim of this report is to calculate the emission and removal factors for every classified land use and forests for the estimation of emissions and removals for the period of 2000 – 2010 for development of the reference level.

In Vietnam the dataset of NFIMAP is available for 4 cycles (1991-1995; 1996-2000; 2001-2005; and 2006-2010), but the quality of these datasets are very different. The dataset of NFIMAP cycle 4 is reported to be the highest quality and this dataset has been reviewed and updated several times. Therefore, this dataset is used for the estimation of emission and removal factors and applied in the nationally developed allometric equations for the NCC for the tree level biomass estimation. The tree level biomass estimation is then compiled for every forest type. The accuracy of emission and removal factors is also assessed

2 DATASET AND METHODS

2.1 Dataset used

Dataset of NFIMAP cycle 4 (2006-2010) is used for the construction of emission and removal factors. This dataset is reported to be at high quality and has also been reviewed and updated several times during the study by JICA and for the preparation of the national reference level for REDD+ (JICA 2012; MARD, 2015). The use of this dataset is consistent with the national reference level and the dataset includes forest cover maps and measurement data of secondary sample plots in primary sample units (PSUs)[1].

Table 2.1 Numbers of primary sample units in inventory cycle 4

ID	Forest types	Number of PSU	Number of SSP
1	EBF-R	78	1,225
2	EBF-M	172	2,398
3	EBF-P	304	5,281
4	Other forest	77	1,080
5	Plantations	42	444
6	Non-forest land	1,325	172
Total		**1,998**	**10,600**

The estimate of the EF and RF is based on measurement data from 753 PSUs and 11,653 SSPs for cycle 4. In these SSPs, information available includes the DBH data of all trees bigger than 5 cm, species name and tree height measured for three trees in each SSP.

Other dataset used for the calculation of the EF and RF are allometric equations that were nationally developed under the support of UN-REDD Vietnam for the NCC[2]. These equations

[1] The dataset is available at FIPI. The access of the data needs to be authorized by VNForest

[2] UN-REDD Vietnam phase I developed numbers of equations for tree level biomass estimation. The equations are validated and can be used at eco-region level and national level with different options of predictors such as DBH, DBH and H, DBH, H and Wood Density (WD).

are available for tree level biomass estimations using different predictors such as DBH, DBH and tree height, DBH, tree height and wood density (Sola et al 2014). The equations available for several woody forests[3] and bamboo forests (3 species) are available at the national and regional level[4].

The research reports related to emission factors for mangrove forest (Phuong *et al*, 2014) and available wood density database (Chave *et al*, 2009; UN-REDD Vietnam, 2012) are also used to calculate EF and RF.

3 METHODS TO GENERATE EF AND RF

3.1 Review and update of the forest dataset

In this work, the updated dataset of NFIMAP cycle 4 is again reviewed and checked independently for elimination of illogical and typo mistakes. This is done by comparing recorded data in field form and digitized dataset. In Vietnam, the National Forest Inventory Program started in 1991 and all requirements for forest inventory including sampling design, field measurement, data analysis and control and reporting is regulated (FIPI, 1995). The main steps for reviewing and updating the forest dataset used for calculation of the EF and RF are as follows:

- Identify and remove the repeated trees caused by data entry mistakes;
- Entry data of missing trees;
- Checking and correcting name of species;
- Checking tree height and DBH by displaying data of DBH and tree height on graphic to find abnormal data (Figure 3.1). This curve is developed for every provinces in the region. The trees with height above red curve and/or below green curve need to be checked.

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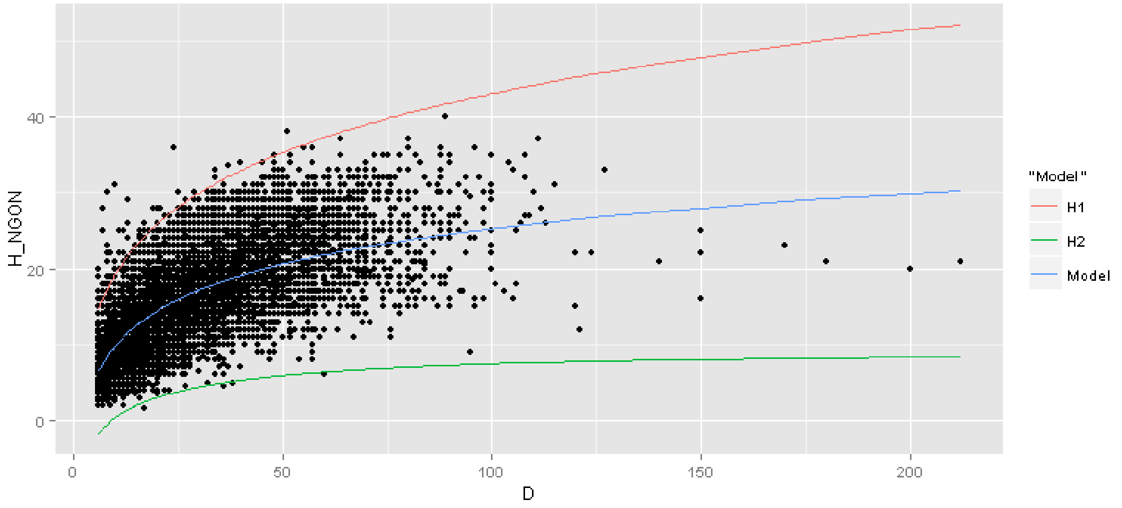
[3] Including evergreen broadleaved forests and deciduous forests

[4] Regional equations available at Northeast, North Central Coast, South Central Coast and Central Highland.

Figure 3.1 Displaying DBH-H relations for checking abnormal data



3.2 Estimation of biomass and carbon stock for all forest types

The AGB of individual trees in the SSPs will be estimated using allometric equations developed by UN-REDD Vietnam for NCC (Gael Sola et al, 2014). Under the UN-REDD Vietnam, a numbers of AE for tree level biomass estimation are developed for national and major eco-regions (northeast, north central coast, central highland and southeast). A single equation is also developed for national scale application. The equations are prepared for evergreen broadleaf forests, deciduous forest and bamboo forests that cover most forest area in Vietnam, particularly evergreen broadleaf forests. There are several choices available for using the developed AE depending on data availability measured such as DBH, tree height and WD. The AE using different predictors have different accuracies. To understand the accuracy of application of different predictors used in the equations, the application of three types of equations for the above biomass estimation, the following AEs are applied.

1) Aboveground biomass estimation of biomass for of evergreen broadleaf forests (including plantations), the following AEs are used:

- AGB = 0.1245*DBH^2.4163 (1)

  (observation = 110; SE = 18.37%; R^2 = 0.99)
- AGB = 0.0421* (DBH^2 * Hmt)^0.9440 (2)

  (observations = 110; SE = 16.23%; R^2 = 0.99)
- AGB = 0.699*(DBH^2 * Hmt * WD/10)^0.940 (3)

  (observations = 110; SE = 13.73%; R^2 = 0.99)

Where:

AGB is above ground biomass expressed in kg;

DBH is diameter at breast height expressed in cm;

Hmt is height of tree along its stem in meter and Hmt = Htop*1.04 (FIPI, 1995);

WD is wood density expressed in gram/cm^3. WD data are taken from national studies (mainly Vietnam Academy of Forest Sciences) that was compiled as a WD database by UN-REDD Vietnam (UN-REDD Vietnam, 2012). In the case where there is no WD data available for tree species, the value of WD will be taken from global WD database, and if not, the average WD value of tree species in Vietnam (0.584) is used[5].

2) Aboveground biomass estimations for bamboo forests, the equations used are based on bamboo species. The equations are as follows (UN-REDD, 2015).

- *Bambusa balcooa*: AGB = 0.1021*DBH^2.2100*H^0.0612 (4)
  (observation = 120; SE = 15.2%; R^2 = 0.92)
- *Dendrocalamus membranaceus*: AGB= 0.1527*DBH^2.1044*H^0.1013 (5)
  (observation = 80; SE = 18.2%; R^2 = 0.91)
- *Bambusa chirostachyoides*: AGB= 0.4514*DBH^1.5022*H^0.3558 (6)
  (observation = 120; SE = 18.2%; R^2 = 0.92)
- *Indosasa angustata*: AGB= 0.3704*DBH^1.6460*H^0.2829 (7)
  (observation = 70; SE = 18.2%; R^2 = 0.92)

After calculation of the tree level AGB of every tree in the SSP, the AGB of the plots is calculated for every forest type existing on the PSU. The general formula for calculation of AGB of measurement plots is as follows:

$$AGB_i = \sum_{j=1}^{n_i} AGB_{ij} \quad (8)$$

Where:

AGBi is total AGB of all trees and bamboos in the measured plot *i*. This is expressed in kg or tonnes of dry mass per plot.

n_i is numbers of measured trees in the plot *i*;

AGB_{ij} is AGB of tree *j* in plot *i*;

To estimate Below Ground Biomass (BGB), it is estimated for every measurement plot using root to shoot ratio (R). As Vietnam has no specific data on R and the development of such a factor is very costly, therefore, the default value of R of 0.20 (IPCC 2006) is used for the calculation of BGB as follows.

$$BGB_i = AGB_i \times 0.20 \quad (9)$$

Total biomass (TB) is calculated for every measurement plot by summing AGB and BGB in each measurement plot:

$$TB_i = AGB_i + BGB_i \quad (10)$$

Carbon stock estimation is accounted for based on biomass and carbon fraction (CF). The formula for calculation is as follows:

$$C_i = TB_i \times CF \quad (11)$$

[5] WD data in Vietnam is available for more 300 species and most of them are natives. As Vietnam has thousands native species and the species vary from region to region therefore, an average WD value of known species is applied for species having no data on WD.

Where:

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

CF is carbon fraction and default value of CF (0.47) is used (IPCC 2006)

After the carbon stock of all measurement plots is estimated, based on area of measurement plot, the carbon stock per ha of forest type is calculated as follows:

$$C\ (tC/ha) \quad = \frac{C_i \times 10^4}{10^3 \times \mathrm{A}} \qquad (12)$$

Where: C*i* is the carbon stock of plot *i*; A is area of measurement plot in m^2 (for woody forest, measurement plot area is 500 m^2 and this is 100 m^2 for bamboo forest).

Once the carbon stock per ha of all forest types is estimated, the average value of carbon stock per ha for every forest type is calculated as follows:

$$\bar{X}_i = \frac{1}{np_i} \sum_{j=1}^{np_i} x_{ij} \qquad (13)$$

Where:

$\bar{X}_i$ is average value of carbon stock for forest type *i*;

x_{ij} is carbon stock of measurement plot *j* for forest type *i*;

Regarding the other forests (bamboo and mangrove forest are combined), its carbon stock is calculated using weighted value. The calculation of carbon stock for this forest type is as follows:

$$C\ (tC/ha) = \frac{Cb*Ab + Cm*Am}{Ab+Am}$$

Where: *Cb* is average carbon stock (tC/ha) of bamboo forest calculated from its biomass using equations;

Ab is area of bamboo forest (ha);

Cm is average carbon stock (tC/ha) of mangrove forests;

Am is area of mangrove forests (ha)

Regarding the mangrove forests, there are no measurement plots in PSU in mangrove forests, however there are a numbers of studies on biomass of mangroves. A review report on biomass and carbon stock suggests that the average weighted carbon stock for mangrove forest in the North (NE, NCC and SCC) is 35.2 tC/ha and for the South (SE and SW) is 64.4 tC/ha and national level is 58.0 tC/ha (Phuong et al 2015).

3.3 Uncertainty assessment of estimated forest carbon stock

The co-variance (CV) for carbon stock of forest type *i* is estimated as follows:

$$CV\%_i = \frac{SE_i \times \sqrt{np_i}}{\bar{x}_i} \times 100 \qquad (14)$$

Where: SE_i is the standard error of carbon stock in the measurement plot of forest type *i*.

np_i is the number of measurement plots for forest type *i*;

As the measurement plot is not sampled randomly, therefore SE is estimated as follows (Tomppo 2010).

$$SE_i = \frac{1}{\sum_{j=1}^{l_i} m_{ij}} \sqrt{\frac{l_i}{l_i - 1} \sum_{j=1}^{l_i} \left(y_{ij} - \bar{x}_i . m_{ij}\right)^2} \qquad (15)$$

Where:

l_i is a minimum number of measurement plot of forest type *i* in a primary sample plot;

y_{ij} is value of all measurement plots of forest type *i* in primary sample plot *j*;

$\bar{x}_i$ is average value of carob stock of forest type *i*;

m_{ij} is number of measurement plots of forest type *i* in a primary sample plots *j*.

The error (E) for carbon stock of forest type *i* is estimated as follows:

$$E\%_i = \frac{t_{\alpha, l_i - 1} \times CV\%_i}{\sqrt{np_i}} \qquad (16)$$

Where:

t_{α, l_i-1} is value of *t* distribution with l_i-1 free degree at confidence of 1-α. In this estimation, confidence used is 90% (α = 0.1).

3.4 Estimation of EF and RF

After completion of calculating average carbon stock for every forest types in the region these values will be used to estimate EF/RF for every change in forests and land uses. As for mangrove forests, there is no measurement plot and carbon stock of mangrove forest is taken from study (Phuong et al 2015). The general formula for estimation of EF and/or RF is as follows and this calculation is based on land use matrices.

$$EF\ or\ RF_{ij}(\mathrm{tCO2e/ha}) = \left(C_i - C_j\right) \times 44/12 \qquad (17)$$

Where:

EF or RF$_{ij}$ is EF or RF when the change incurred from land use *i* to land use[6] *j*. In this estimation, the post carbon stock of deforestation is assumed to be zero (0). Also, carbon stock of non-forestland (rocky mountain, resident and water areas and other land) is considered zero (IPCC 2006).

C_i and C_j is carbon stock per ha of forest type *i* and *j* corresponding to the changes;

If C*i* > C*j*, such change is considered emissions;

If C*i* < C*j*, such change is considered removal or sequestration;

[6] i.e. This is change from one land cover class to another using the same classification scheme used to develop the reference Land cover map and the land cover change analysis

4 RESULTS

4.1 Review of the forest data set

A total of 10,600 secondary sample plots (SSP) of 1,998 PSUs in NFIMAP cycle 4 (of which 10,428 SSP of 673 PSU for forests) was reviewed and updated. The main mistakes found are type and name of tree species. The basic information on forest quality is shown in Table 4.1.

Table 4.1 Basic information on forest quality

Forest types	Average density (trees/ha)	Average wood stock (m^3/ha)
1. EBF-R	594	354
2. EBF-M	560	167
3. EBF-P	1427	64
4. Other forests	7346	12
5. Plantation	500	57

4.2 Forest carbon stock

Time average carbon stock of all classified forest type estimated based on data of NFIMAP cycle 4 and the methods mentioned above. The following table provides carbon stock estimation for forest types (see Table 4.2).

Table 4.2 Average aboveground forest carbon stock (tC/ha) of forest types

Forest types	No. of PSUs	Carbon stock (tC/ha) estimated using DBH	Carbon stock (tC/ha) estimated using DBH and H	Carbon stock (tC/ha) estimated using DBH, H and WD
1. EBF-R	78	148.2	129.2	140.7
2. EBF-M	172	72.2	61.0	65.7
3. EBF-P	304	31.5	27.7	28.8
4. Other forest	77	22.6	22.5	22.5
5. Plantations	42	24.3	21.2	22.4

Analysis of covariance and error of carbon stock estimation shows that there is no significant covariance and error of carbon stock estimated using different predictors. The high values of covariance are found for bamboo forests and plantations and error of carbon estimation for rocky mountain forests is quite high (see Table 4.3 and Annex for details).

Table 4.3 Covariance and error of above forest carbon stock estimation

Forest types	CV (%) of carbon stock estimated using DBH	CV (%) of carbon stock estimated using DBH and H	CV (%) of carbon stock estimated using DBH, H and WD	Error (%) of carbon stock estimated using DBH	Error (%) of carbon stock estimated using DBH and H	Error (%) of carbon stock estimated using DBH, H and WD
1. EBF-R	44.3	43.0	43.7	8.2	8.0	8.1
2. EBF-M	34.7	32.1	34.7	4.3	4.0	4.3
3. EBF-P	77.2	78.5	78.8	7.3	7.4	7.4
4. Other forest	111.2	111.3	111.0	20.8	20.8	20.7
5. Plantations	208.8	220.8	222.4	21.2	21.7	23.5

As the results of forest carbon estimation, it is suggested to use only DBH for forest biomass and carbon stock estimation. Using DBH as a predictor can reduce uncertainty as this data can be measured quite accurately. The measurement of tree height and wood density can also generate its own uncertainty, therefore tree height and WD are used as predictors in forest carbon estimation.

4.3 Estimation of EF and RF

As the analysis, the carbon stock used for calculating EF and RF is shown in Table 4.4

Table 4.4 Carbon stock used for calculation of EF and RF for NCC based on DBH

Land use and forest	Carbon stock (tCO_2/ha)	STDEV (tCO2/ha)	Error (%)	Remarks/sources
1. EBF-R	543.5	240.6	8.2	Calculated
2. EBF-M	264.9	91.8	4.3	Calculated
3. EBF-P	115.5	89.2	7.3	Calculated
4. Other forests	82.9	91.6	20.8	Calculated
5. Plantations	89.0	74.5	24.3	Calculated
6. Non-forest land	0	na	0	IPCC 2006

As mentioned the EF and RF is calculated based on AD for 2 periods of 2000 – 2005 and 2005 – 2010 and carbon stock per ha of land use based on estimation using dataset of NFIMAP cycle 4 and IPCC default values, the EF and RF is estimated in Table 4.5.

Table 4.5 Estimation of EF and RF (tCO_2e/ha) for NCC[7]

2000/2005	2005/2010					
	1	2	3	4	5	6
1. EBF-R	0	279	428	461	454	543
2. EBF-M	-279	0	149	182	176	265
3. EBF-P	-428	-149	0	33	26	115
4. Other forests	-461	-182	-33	0	-6	83
5. Plantation	-454	-176	-26	6	0	89
6. Non-forest	-543	-265	-115	-83	-89	0

5 DISCUSSION

There are several studies on forest carbon stock, however the values of forest carbon stock vary among them. The differences in forest carbon stock estimation are related to the method used and the forest dataset (see Annex 2 & 3 for details). The study of JICA used wood stock data generated by NFIMAP to estimate carbon stock using default value of BCEF, R and CF provided IPCC guidelines (IPCC 2006). In the work of development of national reference and this study, the nationally developed allometric equations are directly used for estimation of forest biomass then converted to forest carbon stock. In addition to that, there is intensive improvement in reviewing and updating the measurement data made during the NFIMAP cycles. However, there are still small differences between the estimation of forest carbon stock prepared for national reference level and for this study. Such differences are normal as in this study, the allometric equations applied are equations developed for NCC and the equations show higher accuracy as the data used for equations construction is taken from NCC. Improving forest dataset also influences estimation results. Given the fact that future improvement of data collection and processing to be used for updating EF and RF is needed if more predictors for biomass estimation are expected to be used. Vietnam is implementing national forest inventory and statistics that is planned to complete in 2016 and that can provide good sources of data for improving EF and RF.

6 CONCLUSIONS AND RECOMMENDATIONS

The above forest carbon stock is estimated using the dataset of NFIMAP cycles 4 and nationally developed allometric equations prepared for the NCC. The accuracy of such estimation is better if more predictors used in the equations, particularly evergreen broadleaf forests. Theoretically the more variable used in equations for estimation of forest biomass can produce better results, however in this study there are concerns about the uncertainties in estimating tree height and wood density. Therefore, the use of DBH for biomass estimation should be sufficient. Other forest types such as bamboo forests, limestone forests and plantation have quite high covariance and error. This may be caused by insufficient sampling plots and/or the sampling design of the NFIMAP as wood stock of these forest types varies greatly. It is suggested that to reduce such variation, the forest classification should be based on carbon stock and there is a need for improvement of data collection and processing in the NFIMAP.

[7] Single C stock for 2000 – 2010, therefore the EF and RF is similar for the period

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Annex 1 Standard deviation and errors for above forest carbon stock estimated using different predictors

Forest type	Carbon stock based on DBH (tC/ha)	STDEV of Carbon stock based on DBH (tC/ha)	Standard error based on DBH (%)	Carbon stock based on DBH &H (tC/ha)	STDEV of Carbon stock based on DBH & H (tC/ha)	Standard error based on DBH & H (%)	Carbon stock based on DBH, H & WD (tC/ha)	Standard error based on DBH, H & WD (tC/ha)	Standard error based on DBH, H & WD (%)
1. EBF-R	148.2	65.6	8.2	129.2	55.5	8.0	140.7	61.5	8.1
2. EBF-M	72.2	25.0	4.3	61.0	19.6	4.0	65.7	22.8	4.3
3. EBF-P	31.5	24.3	7.3	27.7	21.7	7.4	28.8	22.7	7.4
4. Other forests	22.5	25.0	20.8	22.5	25.0	20.8	22.5	25.0	20.7
5. Plantations	24.3	20.3	21.2	21.2	18.1	21.7	22.4	20.9	23.5

Annex 2 Summary of methods for EF and RF development of 3 key studies

Study	Methods and Data sources
JICA (2012)	**Stratification:** 17 land uses are classified, of which 12 are forests **Methods:** EF is estimated for every inventory cycles for period 1990-2010. The EF is used for estimation of emissions and removals for every inventory cycle. Equations used are as follows: EF=(AGB+BGB)*CF*44/12 AGB=GS*BCEF BGB=AGB*R Where: GS – growing stock (m^3/ha); R is root to shoot ratio; CF is carbon faction **Data sources**: GS is calculated based on NFIMAP data (DBH and H). BCEF is taken from default values of IPCC 2006 (range from 0.70 – 4.00 depending on growing stock) R (=0.270) is default value CF (=0.47) is default value
Vietnam's Reference Level submitted to UNFCCC (2016)	**Stratification:** 17 land uses are classified, of which 12 are forests **Methods:** EF and RF are estimated using only NFIMAP data of cycle 4 (2006 – 2010). EF and RF are used to estimate emissions and removals for all inventory cycles. Nationally developed equations at national scale for AGB estimation developed by UN-REDD Vietnam are applied. The equations using three predictors (DBH, H and WD) are used for estimation of AGB of forests (except for mangrove forests and coniferous forests). Estimation of coniferous forest biomass based on its estimated wood volume and biomass expansion factor (BEF = 1.3) **Data sources:** Data of DBH and H are taken from NFIMAP cycle 4 with reviews and updates. WD data is taken from available values of WD in Vietnam and global WD data (Chase et al, 2009) for missing species. Carbon stock of mangrove is derived from literature review Default values of CF (=0.47) and R (=0.20) are used;
Reference Level for NCC under FPCF (2016)	**Stratification:** Two forest types (poor and regrowth evergreen broadleaf forests) are merged. Some forest types not appear in NCC. A total of 12 land uses are used, of which 7 land uses are forests. **Methods:** EF and RF are estimated using only NFIMAP data of cycle 4 (2006 – 2010). EF and RF are used to estimate emissions and removals for 2000 - 2010. Nationally developed equations for AGB estimation for NCC developed by UN-REDD Vietnam are applied. The equations using different options of predictors (DBH; DBH and H; DBH, H and WD) are used for estimation of AGB of forests (except for mangrove forests). Bases on equations application for AGB estimation, the biomass estimation by equations using DBH as predictors are selected. **Data sources:** Data of DBH and H are taken from NFIMAP cycle 4 with reviews and updates. WD data is taken from available values of WD in Vietnam and global WD data (Chase et al, 2009) for missing species. Carbon stock of mangrove is derived from literature review Default values of CF (=0.47) and R (=0.20) are used;

Annex 3 Comparison of estimated carbon stock (tC/ha) using NFIMAP 4 dataset

ID	Forest types	JICA Study	Vietnam's national RL	NCC's RL	Difference of JICA & NCC	Difference between RL & NCC'RL
1	EBF-rich	142.7	137.1	148.2	-5.7	-11.1
2	EBF-medium	76.6	73.9	72.2	4.40	1.7
3	EBF-poor	40.2	31.7	31.5	8.70	0.20
4	Other forests	na	na	22.5	na	na
5	EBF-regrowth	33.6	26.1	na	na	na
6	Deciduous forest	49.9	30.9	na	na	na
7	Bamboo forest	22.1	14.5	na	na	na
8	Mixed timber & bamboo forest	51.8	41.2	na	na	na
9	Coniferous forest	57.0	92.7	na	na	na
10	Mixed broadleaf & coniferous forest	70.6	63.6	na	na	na
11	Mangrove forest	16.7	58.0	na	na	na
12	Limestone forest	43.3	19.1	na	na	na
13	Plantation	26.1	16.3	24.3	1.80	-7.90