Ministry of Agriculture and Rural Development
VIETNAM

Forest Carbon Partnership Facility (FCPF)

Carbon Fund

Emission Reductions Program Document (ER-PD)

Annex 5: Emissions Factor Report

ER Program

Name and Country: Vietnam

Date of Submission or Revision:

October 29, 2017

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	Biennial Updated Report
CF	Carbon Fraction
CI	Confidence Interval
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
FCPF	Forest Carbon Partnership Facility
GHG	Green House Gases
IPCC	Intergovernmental Panel on Climate Change
JICA	Japan International Cooperation Agency
LULUCF	Land use, Land Use Change and Forestry
MAE	Mean Absolute Error
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 Factor
SD	Standard Deviation
SE	Standard Error
SSU	Secondary Sample Unit
tC	Tonne of carbon
UNFCCC	United Nation Framework Convention on Climate Change
VNForest	Vietnam Administration of Forestry
WD	Wood Density

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1 INTRODUCTION

This report is prepared under the Forest Carbon Partnership Facility (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 factors (EFs) for every classified land use and forests for the estimation of emissions and removals for the period of 2005 – 2015 for development of the reference level for NCC.

In Vietnam the dataset of National Forest Inventory, Monitoring and Assessment Program (NFIMAP) is available for 4 cycles (1991-1995; 1996-2000; 2001-2005; and 2006-2010). The modified national reference level for REDD+ submitted to UNFCCC used reference period of 1995 – 2010 (with four time-points 1995, 2000, 2005 and 2010). The activity data (AD) was spatially generated for those years and land use changes were made for 1995-2000; 2000-2005 and 2005-2010. The EFs was calculated using national allometric equations (AEs) and plot data measured in national inventories for 1991-1995, 1996-2000, 2001-2005 and 2006-2010. The estimate of emissions and removals is done for every mentioned period using its AD and EFs.

Since the period of the reference level for the NCC region is 2005-2015, the datasets of NFIMAP cycles 3 and 4 are used for the estimation of EFs applied in the nationally developed AEs for the NCC for the tree level biomass estimation. The tree level biomass estimation is then compiled for every forest type. The uncertainty of EFs is also assessed.

2 DATASET FOR ESTIMATION OF EMISSION FACTORS

Datasets of NFIMAP cycle 3 (2001-2005) and cycle 4 (2006-2010) are used for the construction of emission factors. These datasets have 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 these datasets is consistent with the national reference level and the datasets include measurement data of secondary sample units (SSUs) in primary sample units (PSUs)[1].

Table 2.1 Numbers of secondary sample units (SSUs) in NFIMAP cycles 3 and 4

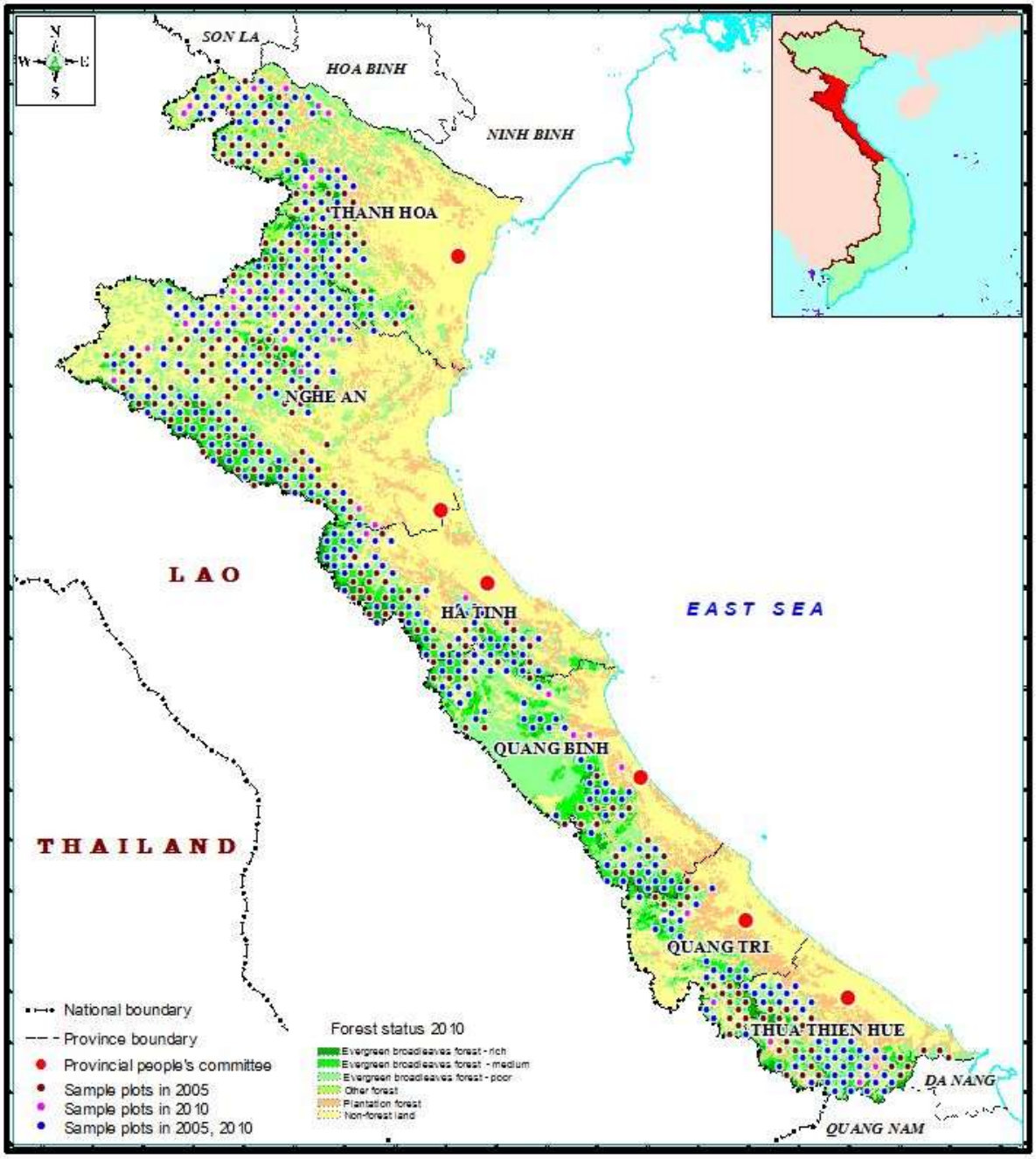
ID	Forest types	Number of SSUs in Cycle 3	Number of SSUs in Cycle 4
1	Evergreen broadleaf – Rich (EBF-R)	2,820	1,225
2	Evergreen broadleaf - Medium (EBF-M)	3,447	2,398
3	Evergreen broadleaf - Poor (EBF-P)	6,215	5,281
4	Other forest	3,422	1,080
5	Plantations	234	444
6	Non-forest land	7,542	5,264
Total		**23,680**	**16,080**

The estimates of the EFs are based on 23,680 SSUs of 592 PSUs for cycle 3 and 16,080 SSUs of 402 PSUs for cycle 4. In these SSUs, information available includes the DBH data of all trees bigger than 5 cm, species name and tree height measured for three trees in each SSU.

Figure 2.1 shows the spatial distribution of PSUs throughout the NCC area. Color coding indicates whether locations were part of the 2005 sample, the 2010 sample, or both.

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

Figure 2.1 Spatial distribution of PSUs throughout the NCC area



The calculation of the EFs is also based on allometric equations that were nationally developed under the support of UN-REDD Vietnam for the NCC[2]. These equations are available for tree level biomass estimations using different predictors such as DBH; DBH and tree height; or DBH, tree height and wood density (Sola et al 2014). The equations for several woody forests[3] and bamboo forests (4 species) are available at the national and regional level[4].

[2] UN-REDD Vietnam phase I developed a number 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).

[3] Including evergreen broadleaf forests and deciduous forests

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

The research reports related to carbon densities for mangrove forest (Phuong *et al*, 2015) is also used to calculate EFs.

Default values provided by IPCC guidelines (IPCC 2006), such as root to shoot ratio and carbon fraction are applied to estimate forest carbon stock.

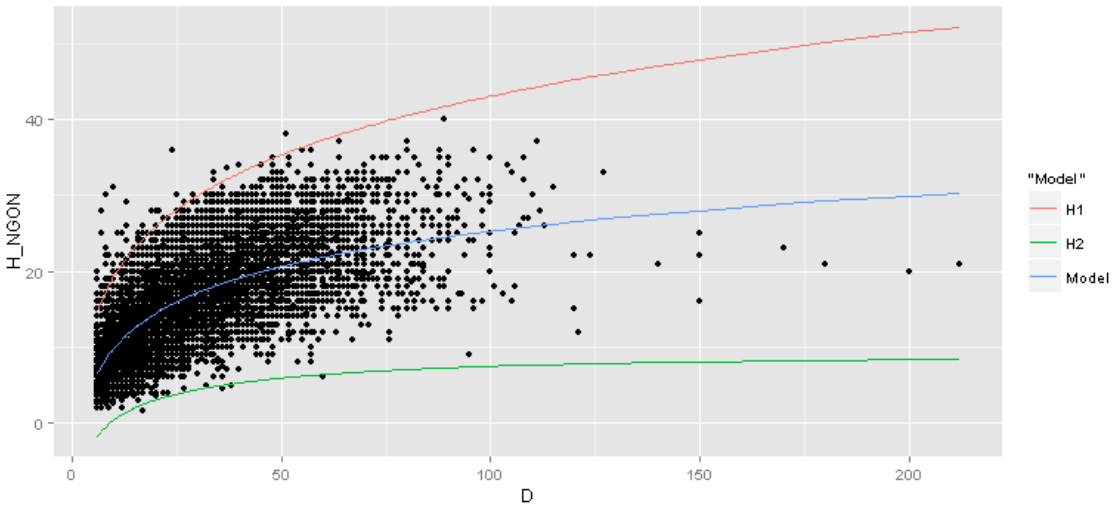
3 METHODS TO GENERATE EMISSION FACTORS

3.1 Review and update of the NFIMAP dataset

In this work, the updated datasets of NFIMAP cycles 3 and 4 are again reviewed and checked independently for elimination of illogical and typo mistakes. This is done by comparing recorded data in field forms and digitized datasets. In Vietnam, the NFIMAP 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 records;
- Checking and correcting names 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 per main forest types (i.e., evergreen broadleaf forest, plantation) in the region. The trees with heights above the red curve or below the green curve need to be checked.

Figure 3.1 Displaying DBH-H relations for checking abnormal data



3.2 Estimation of biomass and carbon densities for all forest types in periods 2001-2005 and 2006-2010

The aboveground biomass (AGB) of individual trees in the SSUs will be estimated using AEs developed by UN-REDD Vietnam for NCC (Gael Sola et al, 2014). Under the UN-REDD Vietnam, a number of AEs for tree level biomass estimation are developed for national and major eco-regions (northeast, NCC, central highland and southeast). A single equation is also developed for national scale application. The equations are prepared for evergreen broadleaf forests, deciduous forests and bamboo forests that cover most forest area in Vietnam, particularly evergreen broadleaf forests. There are several choices available for using the developed AEs depending on data availability measured such as DBH only; DBH and tree height; and DBH, tree height and wood density (WD). The AEs using different predictors have different accuracies. Of these three predictors, DBH can be measured quite accurately. The NFIMAP data can only estimate the tree heights and WD of woody

trees indirectly via height curves and species identification, which can generate additional but often unknown uncertainty. Therefore, tree height and WD are not used as predictors for forest carbon density estimation in this work.

3.2.1. Calculation of aboveground biomass (AGB) for individual trees and bamboos

1) AGB estimation of trees in evergreen broadleaf forests (including plantations): the following AE is used (Huy, 2014):

$$AGB = 0.121155 \times DBH^{2.415395} \quad (1)$$

(observation = 311; MAE% = 33.6%; adjusted R^2 = 0.854)

Where:

AGB is above ground biomass expressed in kg;

DBH is diameter at breast height expressed in cm;

2) Aboveground biomass estimations for bamboo forests, the equations used are based on bamboo species. The equations are as follows (Phuong *et al*, 2014).

- *Bambusa balcooa*:

$$AGB = 0.0612 \times DBH^{2.0848} \times H^{0.2778} \quad (2)$$

(observation = 120; MAE% = n.a; adjusted R^2 = 0.875)

- *Dendrocalamus membranaceus*:

$$AGB = 0.1012 \times DBH^{1.9667} \times H^{0.2778} \quad (3)$$

(observation = 100; MAE% = 16%; adjusted R^2 = 0.875)

- *Bambusa chirostachyoides*:

$$AGB = 0.3558 \times DBH^{1.2154} \times H^{0.2778} \quad (4)$$

(observation = 120; MAE% = n.a; adjusted R^2 = 0.875)

- *Indosasa angustata*:

$$AGB = 0.2829 \times DBH^{1.4306} \times H^{0.2778} \quad (5)$$

(observation = 70; MAE% = n.a; adjusted R^2 = 0.875)

Where:

AGB is above ground biomass expressed in kg;

DBH is diameter at breast height expressed in cm;

H is the height expressed in m.

3.1.2. Calculation of carbon stock for each SSU

Step 1: Estimating AGB of SSU.

Total AGB of trees in each SSU is estimated as the sum of all individual tree AGBs in this SSU.

$$AGB_T_i = \sum_{j=1}^{n_i} AGB_T_{ij} \quad (6)$$

Where AGB_T_i is the total AGB of trees in SSU *i*, n_i is the number of trees in SSU *i*, and AGB_T_{ij} is the AGB of the *j*th tree in SSU *i*.

Total AGB of bamboos in each SSU is estimated as the sum of all individual bamboo AGBs in this SSU.

$$AGB_B_i = \sum_{j=1}^{m_i} AGB_B_{ij} \quad (7)$$

Where AGB_B_i is the total AGB of bamboos in SSU *i*, m_i is the number of bamboos in SSU *i*, and AGB_B_{ij} is the AGB of the *j*th in SSU *i*.

Since the area of tree measurement in each SSU is 500 m^2 but the area of bamboo measurement in each SSU is only 100 m^2, the total AGB of both trees and bamboos in SSU *i*, AGB_i, is:

$$AGB_i = AGB_T_i + 5 \times AGB_B_i \quad (8)$$

The AGB for each SSU is in the unit of kg per 500 m^2. Apply the following formula to convert to the unit of ton per ha:

$$tAGB/ha_i = AGB_i \times \frac{10000}{500 \times 1000} = AGB_i/50 \quad (9)$$

Step 2: Estimating below-ground biomass (BGB) of SSU.

BGB is be estimated for each SSU as follows:

$$tBGB/ha_i = tAGB/ha_i \times R \quad (10)$$

Where $tBGB/ha_i$ is the BGB of SSU *i* in the unit of ton per ha; *R* is the root-to-shoot ratio. As Vietnam has no specific data on R and the development of such factor is very costly, therefore, the default values of *R* of 0.20 for forest type with AGB < 125 tdm/ha and *R* of 0.24 for forests with AGB ≥ 125 tdm/ha (IPCC 2006) are used for calculation of BGB.

Step 3: Estimate total living biomass (including AGB and BGB) for each SSU.

Total living biomass in SSU *i* is the sum of AGB and BGB of this SSU:

$$tB/ha_i = tAGB/ha_i + tBGB/ha_i \quad (11)$$

Step 4: Estimating carbon stock of each SSU.

Carbon stock of SSU *i* in the unit of ton carbon per ha, tC/ha_i, is calculated as follows:

$$tC/ha_i = tB/ha_i \times CF \quad (12)$$

Where *tB/hai* is total living biomass of SSU *i* in ton per ha; *CF* is the carbon fraction coefficient. This work applied the IPCC default value for CF, which is 0.47 (IPCC, 2006).

3.1.3. Calculation of carbon density for each forest type

The carbon density (i.e., average carbon stock per ha)_of forest type *i* is the mean of the carbon stock per ha over all SSUs in this forest type.

$$\overline{tC/ha_i} = \frac{1}{np_i} \sum_{j=1}^{np_i} tC/ha_{ij} \quad (13)$$

Where np_i is the number of SSUs in forest type *i*; tC/ha_{ij} is the carbon stock per ha of SSU *j* in forest type *i*.

Regarding the other forests category (bamboo and mangrove forests are combined), its carbon density is calculated using weighted value as follows:

$$\overline{tC/ha_i} = \frac{Cb * Ab + Cm * Am}{Ab + Am} \quad (14)$$

Where: *Cb* is the carbon density (tC/ha) of bamboo forest calculated from its biomass using equations and plot data;

Ab is area of bamboo forest (ha) derived from a forest cover map;

Cm is the carbon density (tC/ha) of mangrove forests;

Am is area of mangrove forests (ha) derived from a forest cover map.

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 density for mangrove forest in the North (Northeast, NCC and South Central Coast) is 35.2 tC/ha and in the South (Southeast and Southwest) is 64.4 tC/ha and national level is 58.0 tC/ha (Phuong *et al*, 2015).

3.3 Estimation of carbon densities for period 2010-2015

Since plot measurement data for period 2011-2015 are not available and there is no clear trend of carbon change resulted from the change in forest types, therefore we apply "conservative estimate" by assuming the carbon densities of forest types in period 2011-2015 are the same compared to that of period 2006-2010. That means the change in carbon density between 2010-2015 in any given forest type is zero (i.e., no average increase or decrease in carbon density for any given forest type). The carbon density of non-forest land is assumed to be zero (0). We considered other alternatives such as using a value equal to the average of previous inventories, or projecting the recent trend in changing carbon density, but using the 2006-2010 estimates seems the most conservative approach, i.e. less likely to over-estimate actual emissions, and therefore less likely to over-estimate future emissions reductions through ER program implementation.

3.4 Uncertainty assessment of estimated forest carbon densities

Step 1: Calculation of coefficient of variation.

The coefficient of variation of carbon density in forest type *i* is estimated by formula below:

$$CV\%_i = \frac{SE_i \times \sqrt{np_i}}{\overline{tC/ha_i}} \times 100 \quad (15)$$

Where SE_i is the standard error of carbon stocks of SSUs in forest type *i*. Since the sample plots in NFIMAP is a grid of clusters, the standard error is estimated by the equation below (Tomppo, 2010):

$$SE_i = \frac{1}{\sum_{j=1}^{l_i} np_{ij}} \sqrt{\frac{l_i}{l_i - 1} \sum_{j=1}^{l_i} \left(Y_{ij} - \overline{tC/ha_i}.np_{ij}\right)^2} \quad (16)$$

Where l_i is the number of PSU with at least one SSU in forest type *i*; Y_{ij} is the total value of all SSUs in forest type *i* in PSU *j*; np_{ij} is the number of SSUs in forest type *i* in PSU *j*.

Step 2: Calculation of errors.

Error in percentage of carbon density for forest type *i*, $E\%_i$, is calculated by the following formula:

$$E\%_i = \frac{t_{\alpha, l_i - 1} \times CV\%_i}{\sqrt{np_i}} \quad (17)$$

Where t_{α, l_i-1} is the value of the *t* distribution of l_i-1 degrees of freedom for the 1-α confidence interval (CI). In this work, errors are estimated for 95% CI (α = 0.05).

4 RESULTS

4.1 Review of the forest data set

Use the same raw data as the national reference level, but recalculate the estimates of carbon densities using the re-defined forest types (which are aggregates of the forest types used in the national reference level). The raw data used are plot data of cycle 3 (2001-2005) and cycle 4 (2006-2010) to estimate the carbon densities of the forests for two time-points 2005 and 2010. The plot data for NCC are based on 23,680 SSUs of 592 PSUs for cycle 3 and 16,080 SSUs of 402 PSUs for cycle 4. The basic information on forest quality is shown in Table 4.1.

Table 4.1 Basic information on forest quality

Forest types	Cycle 3		Cycle 4	
	Average density (trees/ha)	Average wood stock (m^3/ha)	Average density (trees/ha)	Average wood stock (m^3/ha)
1. EBF-R	513	369.3	594	325.3
2. EBF-M	443	162.8	508	157.6
3. EBF-P	283	66.8	345	59.0
4. Other forests (mainly bamboos)	4	2.9	4	3.0
5. Plantation	407	41.8	492	46.5

4.2 Forest carbon densities

Carbon densities of all classified forest types were estimated based on data of NFIMAP cycles 3 and 4 and the methods mentioned above. The following tables provide carbon density estimation for forest types (see Table 4.2 and Table 4.3).

Table 4.2 Estimation of 2005 forest carbon densities

Forest types	No. of PSUs	No. of SSUs	Carbon density (tC/ha)	Error (%) at 95% CI	SE (%) at 95% CI
1. EBF-R	163	2,820	171.23	15.43	13.38
2. EBF-M	260	3,447	73.41	2.04	0.76
3. EBF-P	410	6,215	31.70	4.69	0.76
4. Other forest	215	3,422	13.00	10.57	0.70
5. Plantations	24	234	20.97	36.01	3.65
6. Non-forest land	n.a.	n.a.	0	n.a.	na

Table 4.3 Estimation of 2010 forest carbon densities

Forest types	No. of PSUs	No. of SSUs	Carbon density (tC/ha)	Error (%) at 95% CI	SE (%) at 95% CI
1. EBF-R	78	1,225	148.50	10.39	7.75
2. EBF-M	172	2,398	71.22	2.85	1.03
3. EBF-P	304	5,286	29.22	6.24	0.93
4. Other forest	96	1,463	14.67	17.95	1.33
5. Plantations	42	444	23.58	25.89	3.02
6. Non-forest land	n.a.	n.a.	0	n.a.	na

It can be observed that the carbon densities of EBF-R, Other forest and Plantations categories have quite high errors. The plantations category has the highest errors in both time periods.

Note that the carbon densities for the “other forest” category in the above tables do not include mangrove forests as there is no PSUs in mangrove forests. Equation (14) is used to calculated the weighted carbon densities for “other forest” that includes mangrove forest. The carbon densities of other forest including mangrove forest are given in Table 4.4.

Table 4.4 Forest carbon densities (tC/ha) of other forest including mangrove

	2001-2005	2006-2010
Area of other forest excluding mangrove (ha)	352,608	341,678
Area of mangrove forest (ha)	1,147	1,535
Carbon density of other forest excluding mangrove (tC/ha)	13.00	14.67
C density of mangrove forest (tC/ha)	35.20	35.20
Weighted C density of other forest including mangrove (tC/ha)	13.08	14.76

Since the area of mangrove forest is very small compared to the area of other forest excluding mangrove, the errors of carbon densities of other forest including mangrove forest can be assumed to be equal to the errors of carbon densities of other forest excluding mangrove forest, which are 10.57 and 17.95 for periods 2001-2005 and 2006-2010, respectively.

5 DISCUSSION

There are several studies on forest carbon densities, however the values of forest carbon densities vary among them. The differences in forest carbon density estimation are related to the method used and the forest dataset (see Appendices 1 & 2 for details). The study of JICA used wood stock data generated by NFIMAP to estimate carbon density using default value of BCEF, R and CF provided in IPCC guidelines (IPCC 2006). In the work of development of national reference level and this study, the nationally developed allometric equations are directly used for estimation of forest biomass density which are then converted to forest carbon density. 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 densities 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 use only DBH as the predictor. 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.

6 CONCLUSIONS AND RECOMMENDATIONS

The forest carbon densities are estimated using the datasets of NFIMAP cycles 3 and 4 and nationally developed allometric equations prepared for the NCC. There is a clear trend of carbon reduction for natural evergreen broadleaf forests, particularly rich and medium forests. However, the opposite trend is found for plantations. Error of carbon stock estimation is highest for plantation and other forests. 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 density and there is a need for improvement of data collection and processing in the NFIMAP.

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Appendix 1. Summary of methods for EF and RF development of 3 key studies

Study	Methods and Data sources
JICA (2012)	**Reference period: 1990-2010** **Stratification:** 17 land uses are classified, of which 12 are forests **Methods:** EF is estimated for every inventory cycles 1-4 (1991-2010). 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 fraction **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)	**Reference period: 1995-2010** **Stratification:** 17 land uses are classified, of which 12 are forests **Methods:** EF and RF are estimated using NFIMAP data of cycles 1-4 (1991 – 2010). EF and RF are used to estimate emissions and removals for all inventory cycles. National allometric equations 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) and WD (500 g/cm^3) **Data sources:** Data of DBH and H are taken from NFIMAP cycles 1-4 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 for AGB < 125 tdm/ha; =0.24 otherwise) are used;
Reference Level for NCC under FPCF (2016)	**Reference period: 2005-2015** **Stratification:** Based on the stratification of National RL but some forest types are aggregates of the forest types used in the National RL (poor evergreen broadleaf, regrowth evergreen broadleaf, limestone and mixed timber-bamboo forests are merged into poor evergreen broadleaf; bamboos and mangrove forests are merged into other forest). Some forest types not appear in NCC. A total of 6 land uses are used, of which 5 land uses are forests. **Methods:** EF and RF are estimated using NFIMAP data of cycles 3 and 4 (2001 – 2010). Carbon densities for 2015 are assumed to equal carbon densities for 2010. EF and RF are used to estimate emissions and removals for period 2005 - 2015. Regional allometric equations for AGB estimation for NCC developed by UN-REDD Vietnam are applied. The equations using DBH as predictor are used for estimation of AGB of forests (except for mangrove forests). **Data sources:** DBH data are taken from NFIMAP cycles 3-4 with reviews and updates. Carbon stock of mangrove is derived from literature review Default values of CF (=0.47) and R (=0.20 for AGB < 125 tdm/ha; =0.24 otherwise) are used;

Appendix 2. Comparison of estimated carbon densities (tC/ha) using NFIMAP Cycle 4 dataset for NCC

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	141.2	148.5	-5.8	-11.4
2	EBF-medium	76.6	70.2	71.2	5.4	2.7
3	EBF-poor	40.2	31.0	29.2	11.0	2.5
4	Other forests	na	na	14.7	na	na
5	EBF-regrowth	33.6	19.2	na	na	na
6	Deciduous forest	49.9	na	na	na	na
7	Bamboo forest	22.1	14.7	na	na	na
8	Mixed timber & bamboo forest	51.8	39.7	na	na	na
9	Coniferous forest	57.0	na	na	na	na
10	Mixed broadleaf & coniferous forest	70.6	na	na	na	na
11	Mangrove forest	16.7	na	na	na	na
12	Limestone forest	43.3	38.2	na	na	na
13	Plantation	26.1	22.1	23.6	2.5	-7.3