T-VER-P-TOOL-01-02

Calculation for carbon stocks and changes in carbon stocks of trees in forest project activities

Version 01

องค์การบริหารจัดการก๊าซเรือนกระจก (องค์การมหาชน) (อบก.)

Thailand Greenhouse Gas Management Organization (Public Organization) (TGO)

1. Introduction

This document is a tool for estimating carbon stocks and changes in carbon stocks in trees in forest project activities, which can be used for estimating carbon stock in both baseline and project scenarios.

2. Relevant Definitions and Reference Values

Details appear in Annex 1

3. Characteristics of involved activities and terms of use

This tool is suitable for estimating carbon stock and change in carbon stock of trees, combining both above-ground and below-ground carbon stocks. The characteristics of these activities can be listed as follow:

1) Estimation of carbon stock and change in carbon stock in the tree in the baseline.
2) Projection (Ex-ante) of carbon stock and change in carbon stock in trees from project implementation
3) Estimation (Ex-post) of carbon stock and change in carbon stock in trees in project implementation

4. Conditions under which carbon stock and change in carbon stock may be estimated as zero

4.1 Carbon stock in trees in the baseline can be accounted as zero if all of the following conditions are met:

1) The pre-project trees are neither harvested, nor cleared, nor removed throughout the crediting period of the project activity
2) The pre-project trees do not suffer mortality because of competition from trees planted in the project, or damage because of project implementation
3) The pre-project trees are not inventoried along with the project trees in monitoring of carbon stocks but their continued existence, consistent with the baseline scenario, is monitored throughout the crediting period of the project activity.

4.2 Changes in carbon stocks in trees in the baseline may be accounted as zero for those lands for which the project participants can demonstrate, through documentary evidence or through participatory rural appraisal (PRA), that one or more of the following indicators apply:

1) Observed reduction in topsoil depth (e.g., as shown by root exposure, presence of pedestals, exposed sub-soil horizons)

2) Presence of gully, sheet or rill erosion; or landslides, or other forms of mass-movement erosion
3) Presence of plant species locally known to be indicators of infertile land
4) Land comprises of bare sand dunes, or other bare lands
5) Land contains contaminated soils, mine spoils, or highly alkaline or saline soils
6) Land is subjected to periodic cycles (e.g., slash-and-burn, or clearing-regrowing cycles) so that the biomass oscillates between a minimum and a maximum value in the baseline

5. Estimating change in carbon stocks in trees at point of time

Carbon stock in trees at one time is estimated by using one of the following methods:

- Stratified random sampling method
- Double sampling method
- Crown cover ratio
- Estimation by modelling of tree growth and stand development
- Others as approved by TGO

5.1 Stratified random sampling method

This method is the basic method for estimating carbon stock by placing the sample plots in one or more stratum. Carbon stock from tree biomass is assessed using the allometries equation appropriate for the species or vegetation in the area. The biomass of trees consists of above-ground biomass (ABG) and below-ground biomass (BLG) with calculation details as follows.

Example 1 At the time of verification, it is known that out of eight parcels of plantation land, three have been harvested in the last two years. Hence the mean tree biomass per hectare in these parcels is low and is relatively homogeneous. Hence these three parcels are treated as one stratum. Of the remaining five parcels, two parcels had poor tree growth compared to the other three. Thus, these five parcels are treated as two separate strata.

Example 2 In a forest plantation raised through assisted natural regeneration, the tree biomass is seen to be distributed unevenly throughout the project area. Using satellite data, it is seen that the distribution of the tree crown cover (which is expected to have a positive correlation with tree biomass) has clearly discernible patterns. Strata boundaries are therefore delineated on the basis tree crown cover estimated from the remote sensing data.

5.1.1 Estimation of Aboveground Biomass (ABG)

Step 1 Place the sample plots that are suitable for the nature of the area, document the type and diameter at chest height, and the total height of the trees in the sample plot area of the project depending on the selected allometric equations

Step 2 Estimate above-ground biomass, select allometric equations that are appropriate for the tree species the area. From the equation that the Greenhouse Gas Management Organization (Public Organization) recommended or other equations that have been studied and published in academic articles and can be identified as suitable for the project area or develop algometric equations for the project area.

Step 3 The above-ground biomass of trees in each sample plot can be estimated using the equation:

$$b_{ABG,p,i} = \sum_{j=1}^{Z} b_{ABG\_j}$$

Where:

$b_{ABG,p,i}$ = The above-ground of tree biomass in sample plot p stratum i (ton of dry weight)

b_{ABG_j} = The above-ground of tree biomass species j estimated from the allometric equation in the sample plot area (ton dry weight)

i = Stratum 1, 2, 3,…m

p = Sample plot 1, 2, 3,…n

j = Tree species 1, 2, 3,…Z

5.1.2 Estimation of Belowground Biomass (BLG)

The below-ground biomass of trees was calculated using the root allometric equation, or the dry weight ratio of roots per plant of each tree species. It can use the ratio recommended by the TGO or other values that have been studied and published in academic articles and can be identified as suitable for the project area, or develop a root-shoot ratio for the project area itself.

Estimation of below-ground biomass in trees in each stratum can be done using the following equation:

$$b_{BLG,p,i} = \sum_{i=1}^{Z} b_{BLG\_j}$$

$$b_{BLG\_j} = b_{ABG,j} \times R_{TREE}$$

Where:

$b_{BLG,p,i}$ = The below-ground biomass of tree in sample plot *p* stratum i (ton of dry weight)

b_{BLG_j} = The below-ground biomass of tree species *j* (ton of dry weight)

b_{ABG_j} = The above-ground biomass of tree species j estimated from the allometric equation in the sample plot area (ton of dry weight)

R_{TREE} = The dry weight ratio of the roots comparing to the plant

i = Stratum 1, 2, 3,...m

p = Sample plot 1, 2, 3,...n

j = Tree species 1, 2, 3,...Z

5.1.3 Estimation of the tree biomass mean from sample plots

When estimating above-ground and below-ground biomass, the mean value of tree biomass per rai in the sample plots can be estimated from the following equation.

$$b_{TREE,p,i} = \frac{(b_{ABG,p,i} + b_{BLG,p,i})}{a}$$

Where:

$b_{TREE,p,i}$ = Mean of tree biomass per rai in sample plots *p* stratum *i* (ton of dry weight per rai)

$b_{ABG,p,i}$ = The above-ground biomass of trees in sample plots *p* stratum *i* (ton of dry weight)

$b_{BLG,p,i}$ = The below-ground biomass of trees in sample plots *p* stratum i (ton of dry weight)

a = Sample plot p (rai)

i = Stratum 1, 2, 3,...m

p = Sample plot 1, 2, 3,...n

5.1.4 Estimation of carbon stock in tree biomass and its uncertainty

$$C_{TREE} = \frac{44}{12} \times CF_{TREE} \times B_{TREE}$$

$$B_{TREE} = A \times b_{TREE}$$

$$b_{TREE} = \sum_{i=1}^{M} w_i \times b_{TREE,i}$$

$$u_c = \frac{t_{VAL} \times \sqrt{\sum_{i=1}^{M} W_i^2 \times \frac{S_i^2}{n_i}}}{b_{TREE}}$$

Where:

C_{TREE}	=	Carbon stock in tree biomass estimation in project area (ton CO2 equivalent)
CF_{TREE}	=	Carbon fraction of tree biomass (tons of carbon per ton of dry weight)
B_{TREE}	=	Tree biomass in the tree biomass estimation in project area (ton of dry weight)
A	=	Sum of project area (rai)
b_{TREE}	=	Mean tree biomass per rai in the project area (ton of dry weight per rai)
W_i	=	Ratio of the area of stratum i (Ai) to the sum of the project area (e.g. Wi = Ai/A) (no unit)
$b_{TREE,i}$	=	Mean tree biomass per rai in stratum i (ton of dry weight per rai)
u_C	=	Uncertainty in C_{TREE}
t_{VAL}	=	The *t*-value for a confidence level of 90 per cent and degrees of freedom equal to n – M, where n is total number of sample plots within the tree biomass estimation strata and M is the total number of tree biomass estimation area

S_i^2	=	Variance of tree biomass in all sample plots in stratum i (ton dry weight per rai)^2
n_i	=	Number of sample plots in stratum i
44/12	=	Molecular mass of carbon dioxide per carbon used to convert units from tons of carbon to tons of carbon dioxide

Mean tree biomass per rai in a stratum and the variance are shown as follows:

$$b_{TREE,i} = \frac{\sum_{p=1}^{n_i} b_{TREE,p,i}}{n_i}$$

$$S_i^2 = \frac{n_i \times \sum_{p=1}^{n_i} b_{TREE,p,i}^2 - (\sum_{p=1}^{n_i} b_{TREE,p,i})^2}{n_i \times (n_i - 1)}$$

Where:

$b_{TREE,i}$	=	Mean tree biomass per rai in stratum i (ton of dry weight per rai)
$b_{TREE,p,i}$	=	Mean tree biomass per rai in plot p of stratum i (ton of dry weight per rai)
S_i^2	=	Variance of tree biomass in all sample plots in stratum i (ton of dry weight per rai)^2
n_i	=	Number of sample plots in stratum i

If the uncertainty (uc) is greater than 10% The value obtained must be deducted from the carbon in the project site's tree biomass (C_{TREE}) according to the ratio in Annex 2.

5.2 Double sampling method

Under this method, a secondary variable is measured in all the sample plots in a stratum and tree biomass is measured in a sub-set of the same sample plots. The mean biomass and its variance are estimated from the measured plot biomass values in the sub-sample and are adjusted through regression of the plot biomass values against the observed plot values of the secondary variable in the sub-sample.

This method is applicable only if there is a linear relationship between the plot biomass values and the plot values of the secondary variable

Remark This method is efficient when spatial distribution of tree biomass in the area is highly heterogeneous and does not show 'block patterns' at significant scale and thus does not allow delineation of strata. The method is more efficient when the cost of obtaining the values of the secondary variable is low compared to cost of measurement of plot biomass, and the correlation between the secondary variable and the measured plot biomass values is high.

Example 1 Spatial distribution of tree biomass in a stratum was highly heterogeneous and it was not efficient to delineate tree biomass sub-strata. The project participants measured basal area in 300 sample plots. In a sub-sample of 50 plots, they also measured plot biomass. This double sampling design reduced the variance of the estimated mean by one half. To achieve the same precision without doubling sampling it would have been necessary to conduct plot biomass measurement in sample plots which would have been costlier.

Example 2 In a large project area the spatial distribution of tree biomass was highly heterogeneous and it was not efficient to delineate tree biomass strata. However, remotely sensed satellite data covering the area was available at a very low cost. An index, namely, Normalized Difference Vegetation Index (NDVI), was constructed from this data which was found to have approximately linear relationship with the per-hectare tree biomass. A double sampling design was adopted with construction of NDVI in 2000 sample plots and measurement of diameter of all trees in 150 sample plots selected from the 2000 plots using systematic selection with a random start. This double sampling design reduced the variance of the estimated mean by one third. To achieve the same precision by measuring fixed-area plots alone would have required measurement of 300 fix-area sample plots which would have been costlier.

Mean tree biomass per rai in landscape layer and the variance is shown as follows:

$$b_{TREE,i} = \frac{\sum_{p=1}^{n_i} b_{TREE,p,i}}{n_i} + \beta \times (\bar{x}' - \bar{x})$$

$$S_i^2 = \frac{n_i \times \sum_{p=1}^{n_i} b_{TREE,p,i}^2 - \left(\sum_{p=1}^{n_i} b_{TREE,p,i}\right)^2}{n_i \times (n_i - 1)} \times (1 - (1 - \alpha) \times \rho^2)$$

Where:

$b_{TREE,i}$ = Mean tree biomass per rai in stratum i (ton of dry weight per rai)

$b_{TREE,p,i}$ = Mean tree biomass per rai in sample plots p stratum i (ton of dry weight per rai)

n_i = Number of sample plots in stratum i

β = Slop of regression curve between tree biomass per rai in sample plots against the secondary variables value of the plot.

$\bar{x}'$ = Mean value of secondary variables across all sample plots

$\bar{x}$ = Mean value of secondary variables across the sub-sample of sample plots in which tree biomass is also measured

S_i^2 = The variance of the mean tree biomass per rai in stratum I (ton dry weight per rai)^2

α = Ratio of number of sample plots in the sub-sample to the number of sample plots in the sample (α<1)

ρ = The correlation coefficient between the secondary variables and the tree biomass per rai in the sample plot, estimated from all subsample plots n the sub-sample

The slope of the regression and the coefficient of correlation are calculated as explained in Appendix 3.

Estimating the carbon stock in tree biomass and the uncertainty use the same equation applied for stratified random sampling (Section 5.1.4 Estimating the carbon stock in tree biomass and uncertainty)

If uncertainty (uc) is greater than 10%, the resulting value shall be deducted from the carbon stock in the tree biomass estimation in project area (C_{TREE}) ratio in accordance with Appendix 2.

5.3 Estimation by proportionate crown cover

This approach applies only to the baseline (ex-ante) where the tree crown cover of the perennial is less than 20% of the forest definition. In which Thailand defines a forest, the crown cover must be at least 30 percent. Therefore, the reforestation project can be assessed based on the proportion of crown cover. Where: In the base case, there is crown cover of less than 6% of perennial plants (mean crown cover less than 20% of 30% = 0.2x0.3 = 0.06)

Carbon stock in trees will be estimated based on the crown cover ratio prior to project implementation. The project area must be stratified according to the crown cover

The estimation of the carbon stock of trees in the baseline is shown as follows:

$$C_{TREE\_BSL} = \sum_{i=1}^{M} C_{TREE_{BSL},i}$$

$$C_{TREE_{BSL},i} = \frac{44}{12} \times CF_{TREE} \times b_{FOREST} \times (1 + R_{TREE}) \times CC_{TREE_{BSL},i} \times A_i$$

Where:

C_{TREE_BSL} = Carbon stock in tree biomass in the baseline (tons of carbon dioxide equivalent)

$C_{TREE_{BSL},i}$ = Carbon stock in tree biomass in baseline in stratum i (tons of carbon dioxide equivalent)

CF_{TREE} = Carbon fraction of tree biomass (tons of carbon per ton of dry weight)

b_{FOREST} = The mean above-ground biomass of the same forest type (ton dry weight per rai)

R_{TREE} = Root-shoot ratio in the baseline (no unit)

$CC_{TREE_{BSL},i}$ =The crown cover of trees in the baseline in stratum i at the start of the project activities, expressed as a fraction. (such as covering of the top 10 percent means = 0.10) (no unit)

A_i = The baseline areas in the stratum i**,** delineated on the basis of tree crown cover at the start of the project activities (Rai)

5.4 Estimation by modelling of tree growth and stand development

This method is used for ex-ante estimation (projection) of carbon stock in tree biomass from ***project operations***, applied by using existing data and tree growth modelling for forecasting stand development and forecasting carbon stock from tree biomass from the above equation. The project developer must select the best tree growth modeling and stand development that is suitable for project area and tree species.

Stand parameters such as stocking (e.g., number of stems per hectare or basal area per hectare), age-class structure, and species composition at different points of time are simulated from assumed (planned) tree planting and management practices (e.g. planting density, survival rate, thinning and pruning operations and their timing).

Tree growth (e.g. diameter or height increment) is simulated by taking into account local tree-growth data from past experience (e.g. age-diameter curves, yield tables, yield curves) while also considering relevant site factors (e.g. soil, terrain, slope, aspect, precipitation) and stand parameters.

5.5 Other methods as per TGO's agreement

Project developer can propose alternative methods for estimating the carbon stock of trees by submitting to TGO for consideration and approval. The estimation method must also be shown in the project design document.

6. Estimating change in carbon stock in trees

Change in carbon stock in trees can be estimated from change in carbon quantity during 2 period, in which both measurements are independent and can utilize different carbon stock estimation methods. The project requesting for certification can use one of the following methods or a combination:

- Estimation of the change from re-measurement in the sample plot
- Estimation of the differences in carbon stock
- Estimation of the proportion of crown cover
- Demonstrating positive change with "no reduction from the original"
- Other methods as approved by the TGO

6.1 Estimation of the change from re-measurement in the same plot

This method is applicable only to the estimation of carbon changes in trees to monitor project activities by repeating measurements in the sample plots between successive periods and the change in biomass derived from biomass per area of the second sample plot minus the biomass per area of the first sample plot.

This method is effective when the project area is constantly changing in relation to each other e.g. no cutting of the logs from the site or not planting more trees in the area after registering the project.

Change in carbon stock and uncertainty are estimated as follows.

$$\Delta C_{TREE} = \frac{44}{12} \times (CF_{TREE} \times \Delta B_{TREE})$$

$$\Delta B_{TREE} = A \times \Delta b_{TREE}$$

$$\Delta b_{TREE} = \sum_{i=1}^{M} w_i \times \Delta b_{TREE,i}$$

$$u_{\Delta C} = \frac{t_{VAL} \times \sqrt{\sum_{i=1}^{M} W_i^2 \times \frac{S_{\Delta,i}^2}{n_i}}}{|\Delta b_{TREE}|}$$

Where:

ΔC_{TREE} = Change in carbon stock in trees between two times t_1 and t_2. (tons of carbon dioxide equivalent)

CF_{TREE} = Carbon fraction of tree biomass (tons of carbon per ton of dry weight)

ΔB_{TREE} = Change in tree biomass within the biomass estimation in the project area (ton of dry weight)

A = Sum of project area (rai)

Δb_{TREE} = Mean change in tree biomass per rai within project area (ton of dry weight per rai)

W_i = Ratio of the area of stratum i (Ai) to the sum of all project areas (e.g. Ai/A); no unit

$\Delta b_{TREE,i}$ = Mean change in carbon stock per rai in tree biomass in stratum i (ton dry weight per rai)

$u_{\Delta C}$ = Uncertainty in ΔC_{TREE}

t_{VAL} = t value at 90% confidence level and degree of freedom equals n-M when: n is the total number of sample plots in the landscape and M is the total number of project area for which tree biomass is estimated.

$S_{\Delta,i}^2$ = The variance of mean change in tree biomass per rai in the stratum i (ton dry weight per rai)^2

n_i = Number of sample plots in the stratum i when tree biomass is re-measured

Mean change in tree biomass per rai and related variances are estimated as follows.

$$\Delta b_{TREE,i} = \frac{\sum_{p=1}^{n_i} \Delta b_{TREE,p,i}}{n_i}$$

$$S_{\Delta,i}^2 = \frac{n_i \times \sum_{p=1}^{n_i} \Delta b_{TREE,p,i}^2 - \left(\sum_{p=1}^{n_i} \Delta b_{TREE,p,i}\right)^2}{n_i \times (n_i - 1)}$$

Where:

$\Delta b_{TREE,i}$ = Mean change in tree biomass per rai in stratum i (ton of dry weight per rai)

$\Delta b_{TREE,p,i}$ = Change in tree biomass per rai in the sample plot p, stratum i (ton dry weight per rai).

$S_{\Delta,i}^2$ = The variance of the mean change in tree biomass. per rai in stratum i (ton of dry weight per rai)^2

n_i = Number of sample plots in stratum i Where: tree biomass is re-measured

If the $u_{\Delta C}$ estimated from the equation is greater than 10%, the resulting value shall be deducted with the amount of carbon change in the tree (ΔC_{TREE}) according to the ratio in Annex 2.

6.2 Differences in carbon stock estimation

This method estimated the change in the carbon stock of trees based on the difference between two successive and independent carbon stock estimations. This method is applicable when the correlation between the plot biomass values on the two occasions is absent or weak e.g. when there has been harvest or disturbance in a stratum after the first estimation, resulting in spatial re-distribution of tree biomass in the stratum.

Changes in the carbon stock in trees and their uncertainty can be estimated from the following equation

$$\Delta C_{TREE} = C_{Tree,t_2} - C_{TREE,t_1}$$

$$u_{\Delta C} = \frac{\sqrt{(u_1 \times C_{TREE,t1})^2 + (u_2 \times C_{TREE,t2})^2}}{|\Delta C_{TREE}|}$$

Where:

ΔC_{TREE} = Change in carbon stock in trees between two times t1 and t2. (tons of carbon dioxide equivalent)

C_{TREE,t_1} = Carbon stock in trees at time t1

(Tons of Carbon Dioxide Equivalent)

Remarks

1. The first verification C_{TREE,t_1} is defined as the amount of carbon stock in the trees prior to the project start. $(C_{TREE,t_1} = C_{TREE\_BSL})$ However, it may be assigned a value of 0 if the zero-carbon change condition is met in the base case.
2. Although C_{TREE,t_1} is made to be a conservative value. from the previous verification, but this estimation uses the measured C_{TREE,t_1} values. (not deducted)

C_{TREE,t_2} = Carbon stock in trees at time t2

(tons of carbon dioxide equivalent)

$u_{\Delta C}$ = Uncertainty of ΔC_{TREE}

u_2, u_1 = Uncertainty of C_{TREE,t_2} and C_{TREE,t_1} in sequence

If the estimated uncertainty $(u_{\Delta C})$ is greater than 10%, the resulting value must be offset with the amount of carbon change in the tree (ΔC_{TREE}) according to the ratio in Appendix 2

6.3 Estimation by proportionate crown cover

This method is only used to ***estimate the change in carbon stock for baseline*** where the crown cover is less than 20% in Thailand, which Thailand defines as “forest”, where the crown cover is at least 30%. A reforestation project can be used to estimate the proportion of crown cover where the baseline of crown cover is less than 6% of perennial crown cover (meaning crown cover is less than 20% of the percentage) 30 = 0.2x0.3 = 0.06)
The change in the carbon stock of trees in the baseline is estimated as follows.

$$\Delta C_{TREE\_BSL} = \sum_{i=1}^{M} \Delta C_{TREE_{BSL},i}$$

$$\Delta C_{TREE_{BSL},i} = \frac{44}{12} \times CF_{TREE} \times \Delta b_{FOREST} \times (1 + R_{TREE}) \times CC_{TREE_{BSL},i} \times A_i$$

Where:

ΔC_{TREE_BSL} = Mean of annual change in the carbon stock of the baseline tree (tons of carbon dioxide equivalent per year)

$\Delta C_{TREE_{BSL},i}$ = Mean of annual change in baseline of tree carbon stock in stratum i (tons of carbon dioxide equivalent per year)

CF_{TREE} = Carbon fraction of tree biomass (tons of carbon per ton of dry weight)

Δb_{FOREST} = The constant of the mean annual increase in the above-ground biomass of same forest area (ton dry weight per rai per year)

Remark tree biomass may reach a steady state due to the fact that the stable growth interval of the tree is zero or insignificant, which is a characteristic of tree growth biology. Estimated from the biomass enhancement rate constant. Therefore, Δb_{FOREST} is set to 0 when tree biomass in the base case to steady state, with a period of stable biomass being 20 years after the start of the reforestation project. Unless transparent and verifiable information is provided to prove different years.

R_{TREE} = Root-shoot ratio of tree in baseline (no units)

$CC_{TREE_{BSL},i}$ = The crown cover for trees in the baseline in the stratum i at the start of the project activities, expressed as a fraction. (such as covering of the top 10 percent means = 0.10 (no unit)

A_i = The baseline areas in the stratum i**,** delineated on the basis of tree crown cover at the start of the project activities (Rai).

6.4 Demonstration of positive change with “no reduction”

This method is used only to estimate changes in the carbon stock of trees from ***project operation***. Project owners will need to demonstrate that the carbon stock of trees in one or all of the stratum has not decreased from previous investigations by correlating tree biomass and prove that:

1) No wood teeth were removed from the area after the previous verification.
2) The trees are not disturbed by other factors such as diseases and insects, forest fires, etc., which will cause a reduction in the carbon stock of the trees.
3) Data from remote sensing or surveys to show crown cover or the persistence of trees after previous verification.

When these three conditions are met in each stratum, changes in trees' carbon stock may be based on conservation principles or zero estimates.

Remark This is appropriate if the project developer wishes to submit a document in the process of verifying and certifying the unit of greenhouse gases at the time of the increase in the biomass of the forest. But it may not be worth it if surveys such as when requires periodic credit verification and certification to check the validity of the certified credit and expect few new certified credits.

6.5 Others as approved by TGO

Project developers can propose other methods for estimating the carbon change of trees by proposing to the TGO for consideration and approval. The estimation method must also be shown in the project proposal.

7. Estimating carbon stock in sapling at a point of time

Estimating carbon stock in sapling at any given time uses the estimation method in the sample plot, which is similar to other estimating carbon stock in trees such as stratified sample plot and double sampling, using the same plots for tree sampling without deduction of uncertainty. The estimation can be done as follows:

Carbon stock estimates in wood biomass are as follows:

$$C_{SAP} = \frac{44}{12} \times CF_{SAP} \times B_{SAP}$$

$$B_{SAP} = A \times b_{SAP}$$

$$b_{SAP} = \sum_{i=1}^{M} w_i \times b_{SAP,i}$$

Where:

C_{SAP} = Carbon stock in shrub biomass (tons of carbon dioxide equivalent)

CF_{SAP} = Carbon fraction of shrub biomass (tons of carbon per ton of dry weight)

B_{SAP} = Shrub biomass (ton of dry weight)

A = Sum of project area (rai)

b_{SAP} = Mean change in shrub biomass per rai (ton of dry weight per rai)

w_i = Ratio of the area of stratum i (Ai) to the sum of all project areas (e.g. Ai/A); no unit

$b_{SAP,i}$ = Mean change in carbon stock per rai in shrub biomass in stratum i (ton dry weight per rai)

8. Estimating carbon changes in sapling

Change in carbon stock in sapling from the same plot can be estimated as follow:

$$\Delta C_{SAP} = \frac{44}{12} \times (CF_{SAP} \times \Delta B_{SAP})$$

$$\Delta B_{SAP} = A \times \Delta b_{SAP}$$

$$\Delta b_{SAP} = \sum_{i=1}^{M} W_i \times \Delta b_{SAP,i}$$

Where:

ΔC_{SAP} = Change in carbon stock in sapling (tons of carbon dioxide equivalent)

CF_{SAP} = Carbon fraction of sapling biomass (tons of carbon per ton of dry weight)

ΔB_{SAP} = Change in sapling biomass within the biomass estimation in the project area (ton of dry weight)

A = Sum of project area (rai)

Δb_{SAP} = Mean change in sapling biomass per rai within project area (tons of dry weight per rai)

W_i = Ratio of the area of stratum i (Ai) to the sum of all project areas (e.g. Ai/A); (no unit)

$\Delta b_{SAP,i}$ = Mean change in carbon stock per rai in sapling biomass in stratum i (ton dry weight per rai)

9. Relevant Parameters

9.1 Parameters not required monitoring

Parameter	CF_{TREE}, CF_{SAP}
Unit	Tons of carbon per tons of dry weight
Meaning	Carbon fraction of tree biomass
Source of information	Option 1: 2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories: Volume 4 Agriculture, Forestry and Other Land Use Option 2: As specified by the TGO in the reference manual for the development of the Voluntary Greenhouse Gas Reduction Project according to the standards of Thailand Forestry and Agriculture Option 3: Values derived from research published in academic papers that are recognized and identifiable as appropriate for the project area.
Remark	-

Parameter	R_{TREE}, R_{SAP}
Unit	Ton of dry weight of roots per ton of dry weight of shoot
Meaning	Root-shoot ratio of tree
Source of information	Option 1 2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories: Volume 4Agriculture, Forestry and Other Land Use Option 2 As specified by the TGO in the reference manual for the development of the Voluntary Greenhouse Gas Reduction Project according to the standards of Thailand Forestry and Agriculture Option 3 Values derived from research published in academic papers that are recognized and identifiable as appropriate for the project area.

Remark	-

Parameter	44/12
Unit	-
Meaning	Molecular mass of CO2 to carbon to convert the unit from tons of carbon to tons of carbon dioxide.
Source of information	-
Remark	-

Parameter	b_{FOREST}
Unit	Tons of dry weight per rai
Meaning	Default above-ground biomass in the same forest type
Source of information	Option 1 2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories: Volume 4 Agriculture, Forestry and Other Land Use Option 2 As specified by the TGO in the reference manual for the development of the Voluntary Greenhouse Gas Reduction Project according to the standards of Thailand Forestry and Agriculture Option 3 Values derived from research published in academic papers that are recognized and identifiable as appropriate for the project area.
Remark	-

Parameter	Δb_{FOREST}
Unit	Tons of dry weight per rai in a year
Meaning	Default mean annual increment of above-ground biomass in the same forest type
Source of information	Option 1 2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories: Volume 4 Agriculture, Forestry and Other Land Use Option 2 As specified by the TGO in the reference manual for the development of the Voluntary Greenhouse Gas Reduction Project according to the standards of Thailand Forestry and Agriculture

	Option 3 Values derived from research published in academic papers that are recognized and identifiable as appropriate for the project area.
Remark	-

9.2 Parameters required monitoring

Parameter	A
Unit	rai
Meaning	Total project area
Source of information	- Area exploration - Use satellite/aerial imagery
ความถี่ในการติดตาม	Following a cycle of follow-up assessments for certification
Remark	-

Parameter	Ai
Unit	rai
Meaning	A sample plot area where sample data is surveyed for estimating carbon stock
Source of information	- Determining the size of the sample plot area of the project - Use satellite/aerial imagery
ความถี่ในการติดตาม	Following a cycle of follow-up assessments for certification
Remark	-

Parameter	$CC_{TREE_{BSL},i}$
Unit	No unit
Meaning	Crown cover of tree in stratum i of the baseline
Source of information	- Area exploration - Use satellite/aerial imagery
ความถี่ในการติดตาม	one time measurement before starting the project
Remark	-

10. References

1) Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities (AR-TOOL14 Version 04.2)
2) T-VER tool: T-VER-TOOL-FOR/AGR-01 Calculation for Carbon Stock) (Version 4)
3) 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 4 Agriculture, Forestry and Other Land Use
4) A/R Methodology Tool "Calculation of the number of sample plots for measurements within A/R CDM project activities"
5) Manual Tree characteristics for A/R CDM Project (2554)

Annex

Annex 1 Relevant Definitions

Uncertainty	The mean value of the estimated Parameter equal to the estimated standard error of the mean at the 90% confidence level divided by the mean. expressed as a percentage to assess and control the sampling uncertainty. <u>Example:</u> Mean above-ground biomass of trees = 45.328 Tons of dry weight per rai Sample size = 34 Standard deviation = 12.776Tons of dry weight per rai The estimated standard error of the mean: SEM = $12.776/\sqrt{34}$ = 2.191 Tons of dry weight per rai SEM at 90 percent confidence level = 2.191 x $t_{(0.1,33)}$ = 2.191 x 1.692 = 3.707Tons of dry weight per rai The mean above-ground biomass of trees is uncertain = (3.707/45.328) ×100 = 8.18 %
Conservative value of a parameter	The value is used when the estimations tend to result in underestimation, or the evaluation of the parameters must be conservative.
Species	Types of plants grown in the project area can reference groups of similar species In biomass assessment, for example, using the equation allometry, etc.
Tree	tree, or woody plant, or lumber and longevity for many years, with a height of more than 1.30 m and a diameter of 1.30 m at an altitude of 4.50 cm or more, except shrubs

Plot biomass	Biomass of trees per 1 rai of area.
Above-ground biomass	The dry weight of all parts of the tree above the ground are the trunk, branches, leaves, flowers and fruits.
Below-ground biomass	dry weight of the below-ground part of the tree In the case of mangrove forests, it refers to the biomass of roots both below-ground and on the soil.
Sapling	A tree that meets the definition of a tree. which exceeds 1.30 meters in height but has a diameter of 1.30 meters less than 4.50 centimeters
Allometric equations	The allometric equation is the equation of the relationship between the diameter and/or the total height of the tree, which is used to calculate the dry weight of trees
Diameter at Breath Height: DBH	The diameter of the tree was measured at an altitude of 1.30 meters from the ground or according to the selected biomass estimation equation conditions

Annex 2 Uncertainty Deduction

The results of estimations with high uncertainty can be applied when the estimation is conservative. This annex demonstrates steps for estimating uncertainty to conservatively evaluate the parameters (e.g. the amount of carbon in trees).

When the mean of uncertainty of the parameter's evaluation is greater than 10%, the mean is adjusted up or down by the percentage of uncertainty as follows:

Uncertainty discount factors

Uncertainty: U	Deduction (percentage of uncertainty)	Usage
U ≤ 10%	0%	<u>Example</u> Mean biomass = 60 ± 9 tons dry weight/rai Uncertainty = 9/60 x 100 = 15% Discount = 25% x 9 = 2.25 tons of dry weight/rai Discount calculations based on conservation principles are as follows: Base case = 60+2.25 = 62.25 tons of dry weight/rai Project implementation = 60-2.25 = 57.75 tons of dry weight/rai
10<U≤15	25%	
15<U≤20	50%	
20<U≤30	75%	
U>30	100%	

Annex 3 Calculation of the correlation coefficient and regression slope

$$\beta = \rho \times \frac{S_y}{S_x}$$

$$\rho = \frac{\sum_{i=1}^{n}\{(x_i - \bar{x})(y_i - \bar{y})\}}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \times \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Where: β = The slope of the regression graph

ρ = Sample correlation coefficient

S_y, S_x = Sample Standard Deviation

x_i = independent variable(x)

$\bar{x}$ = mean of independent variables (x)

y_i = dependent variable(y)

$\bar{y}$ = the mean of the dependent variable (y)

n = number of data values in each data set

Document information			
Version	Amendment	Entry into force	Description
01	--	1 March 2023	-