T-VER-P-TOOL-01-07

Demonstrating Appropriateness of Equations for Estimation of Aboveground Tree Biomass in Forest Project Activities

Version 01

1. Introduction

This document is a tool for selecting the appropriate allometric equation, the use of volume tables or volume equation together with biomass expansion factor (BEF) and basic wood density for in estimating the aboveground tree biomass as well as in estimating carbon stocks and change in carbon stocks of trees in forest project activities. This tool can be used to estimate greenhouse gas emissions in both baseline and project scenarios.

2. Relevant definitions and reference values

Details appear as in Annex 1

3. Characteristics of relevant activities and conditions

This tool is used for selecting the appropriate allometric equation of the stem volume in combination with the relevant coefficients to calculate the aboveground biomass of the trees according to the nature of the activities involved and its use conditions as per selected methodology.

4. Selection of appropriate allometric equation

4.1 The use of allometric equation to estimate tree biomass by pre-project implementation.

To ex-ante estimation, before project implementation, any equation can be used to estimate the aboveground biomass of trees.

4.2 The use of allometric equations to estimate tree biomass by post-project projection.

In ex post estimation, after project implementation, an equation can be used to estimate the aboveground biomass of trees as follows:

4.2.1 Allometric equation used for each species or a group of species of trees that grows in similar topography, climatic characteristics, and landscape conditions to those in the area project activity is implemented can be selected to be used in post-project projection if at least one of the following conditions is satisfied.

      <u>Option 1</u>   The allometric equation is used for surveying the country's forest resources or for national GHG inventory

      <u>Option 2</u>   The allometric equation has been used in commercial forestry sector for 10 years or more

Option 3   The allometric equation was derived from data set of at least 30 trees, and the value of coefficient of determination (R^2) obtained was not less than 0.85.

4.2.2 Other use of equations that do not satisfy the conditions in clause 4.2.1 can be used if the satisfaction of original equations can be demonstrated as per the following conditions.

1) Selection of sample trees

Allometric equation used for each species or a group of species of trees must be used for at least 10 sample trees growing in similar topography, climatic characteristics, and landscape conditions to those in the area project activity is implemented. The sample trees must have a good representation in term of tree sizes of the project area. If an allometric equation is used for biomass computation for more than one stratum within project boundary, the selection of trees must be good representation across all such strata for which the allometric equation is to be demonstrated.

2) Biomass estimation of sample trees

Estimation of the stem volume of a sample tree is measured from its diameter at breast height (DBH) and/or height of the tree as a preliminary data/input as independent variable of the allometric equation which has the general form as the equation (1)

$$Y = aX^b \tag{1}$$

Y	means	Biomass or dry weight of parts of a tree such as trunks, branches, leaves or aboveground parts (kg).
X	means	Independent variables obtained from tree measurements. There may be one or more variables, such as the diameter and/or height of the tree. The most common independent variables are D^2H and D^2.
D	means	Diameter of the tree (centimeters)
H	means	Height of the tree (meters)
a, b	means	relationship constant

3) Measurement of biomass of sample trees มี 2 วิธีการ

Method 1 Direct measurement of biomass of sample trees

by cutting down a sample tree and weigh the total of each sample tree in the field. and collect samples for drying and dry weighing for calculating biomass (dry weight of the sample tree)

Method 2 Direct measurement of stem volume and estimation of biomass of sample trees, มี 2 วิธีการ

- Water displacement method

  the sample tree is felled and its stem is cut into sections that fit into a water tank (e.g. xylometer). The pieces ate then put it in the tank (below the water) and the volume of water displaced is measured. Repeat the process for all the sections of stem and volumes of the sections are summed up to obtain the tree stem volume (stem volume, V_{STEM}).

- Sectional diameters method

  the sample tree is felled and its stem is cut into sections, the length is not more than 2 meters, and stem diameter at the middle point of each section is measured. The volume of a section of stem can be calculated from equations (2) and (3) respectively.

$$V_i = \frac{\pi \times D^2{}_{M,i} \times L_i}{4} \times 10^{-4} \qquad (2)$$

V_i	means	Volume of i-section of stem (cubic meter)
$D_{M,i}$	means	Diameter at the middle point of the i-section of stem (cm)
L_i	means	Length of the i-section of stem (meters)

$$V_{STEM} = \sum_i V_i \qquad (3)$$

V_{STEM}	means	Tree stem volume (cubic meter)
V_i	means	Volume of i-section of stem (cubic meter)

Estimating aboveground biomass of sample trees, both ways to water displacement method or sectional diameters method, can be done by multiplication of the appropriate basic wood density or multiplication of the default biomass expansion factor (BEF), which has a value of 1.15, or may take the biomass coefficient from the reference value. Others that are suitable or as prescribed by TGO.

4) Comparing the measured and the predicted tree biomass

Comparison of tree biomass as measured and predicted by paired-t test based on statistical principles as detailed in Annex 2

5) The use of allometric equation in biomass estimation for baseline and in the project.

Using the allometric equation to estimate biomass for the baseline and/or in the project according to conservative principles (conservative use of an equation), it can be done as follows:

Case 1 The allometric equation is suitable for estimating biomass for the baseline and in the project if the p-value from the paired t-test according to no. 4) above is greater than or equal to 0.90.

Case 2 The allometric equation is only suitable for estimating biomass for the baseline. If the mean of measured tree biomass is less than the mean of predicted tree biomass and any one of the following conditions is satisfied

- The p-value from the paired t-test according to item 4) is less than 0.20 (as detailed in the test in Annex 2).

- The confidence interval for the difference between the mean at the 90% confidence level is not equal to zero. (as detailed in the test in Annex 3)

Case 3 The allometric equation is only suitable for estimating biomass in the project, if the mean value of tree biomass is greater than the estimated mean and satisfy one of the following conditions

- The p-value from the paired t-test according to item 4) is less than 0.20 (as detailed in the test in Annex 2).

- The confidence interval for the difference of the mean at the 90% confidence level is not equal to zero. (as detailed in the test in Annex 3)

6) Improvement of allometric equation

The allometric equation that does not fit the conditions mentioned in no. 5) can be improved by methods such as coefficient improvement, so that the test results meet the above conditions.

5. Development and selection of appropriate volume equations for estimation of tree stem volumes.

5.1 Estimation of tree stem volume

For *ex-post* estimation, the tree volume equation or the tree volume table can be used to estimate the tree's volume as follows:

5.1.1 Equation of tree volume or table of specific tree volumes for each species or a group of species of trees growing in similar topography, climatic characteristics, and landscape conditions to those in the area project activity is implemented can be selected for use in *ex post* estimation if at least one of the following conditions is satisfied .

<u>Option 1</u>	Volume table or volume equation is used for surveying the country's forest resources or for national GHG inventory
<u>Option 2</u>	Volume table or volume equation has been used in commercial forestry sector for 10 years or more
<u>Option 3</u>	Volume table or volume equation was derived from data set of at least 30 trees, and the value of coefficient of determination (R^2) obtained was not less than 0.85.

5.1.2 Volume table or volume equation that does not satisfy the conditions in no. 5.1.1 can be applied if the original equation meets the following conditions can be demonstrated:

1) Selection of sample trees

Volume table or volume equation specific for each species or a group of species of trees must be used for at least 10 sample trees growing in similar topography, climatic characteristics, and landscape conditions to those in the area project activity is implemented. The sample trees must have a good representation in term of tree sizes of the project area. If volume equation is used for biomass computation for more than one stratum within project boundary, the selection of trees must be good representation across all such strata for which the volume equation is to be demonstrated.

2) Estimation of predicted stem volume of sample trees

Estimation of the stem volume of a sample tree is measured from its diameter at breast height (DBH) and/or height of the tree as a preliminary data/input as independent variable of volume table or volume equation which has the general form as the equation (4)

$$V = f(D) \text{ or } V = f(D,H) \tag{4}$$

V means   Volume of stem (cubic meter)

D means   the diameter of the tree (cm)

H means   the height of the tree (meters)

3）Measurement of the stem volume of a sample tree can be done by one of the following methods.

Method 1 Water displacement method

- the sample tree is felled and its stem is cut into sections that fit into a water tank (e.g. xylometer). The pieces ate then put it in the tank (below the water) and the volume of water displaced is measured. Repeat the process for all the sections of stem and volumes of the sections are summed up to obtain the tree stem volume (stem volume, V_{STEM}).

Method 2 Sectional diameters method

- the sample tree is felled and its stem is cut into sections, the length is not more than 2 meters, and stem diameter at the middle point of each section is measured. The volume of a section of stem can be calculated from equations (2) and (3) respectively.

4) Comparing the measured and the predicted stem volume

Comparison of stem volumes from measurements and estimates with paired-t test based on statistical principles as detailed in Annex 2.

5）Use of the volume equation for estimating mean stem volume in baseline and in project

The volume table or volume equation is appropriate for estimation of tree stem volume, in the baseline and in the project conservative use of an equation as follows:

Case 1 Volume equation or volume table is <u>suitable for estimating biomass for the baseline and in the project</u> if the p-value from the paired t-test according to no. 4) above is greater than or equal to 0.90.

Case 2 Volume equation or volume table is <u>only suitable for estimating biomass for the baseline</u>. If the mean of measured tree biomass is less than the mean of predicted tree biomass and any one of the following conditions is satisfied.

- The p-value from the paired t-test according to no. 4) is less than 0.20 (as detailed in the test in Annex 2.

- The confidence interval for the difference of the mean at the 90% confidence level is not equal to zero. (as detailed in the test in Annex 3)

Case 3 Volume equation or volume table is <u>only suitable for estimating biomass in the project</u>, if the mean value of tree biomass is greater than the estimated mean and satisfy one of the following conditions

- The p-value from the paired t-test according to item 4) is less than 0.20 (as detailed in the test in Annex 2).

- The confidence interval for the difference of the mean at the 90% confidence level is not equal to zero. (as detailed in the test in Annex 3)

6) Improvement of the stem volume equation

The volume equation or volume table that is not suitable according to the conditions described in no. 5) can be improved by various methods such as improving coefficients, so that the test results meet the above conditions.

6. Using equations for estimating aboveground tree biomass

The aboveground tree biomass can be estimated using allometric equation and volume equations or volume tables, together with the biomass expansion factor (BEF) and basic wood density. The selection of equations and coefficients requires consideration of the appropriateness of the volume equation or volume table, biomass and the density of the wood according to the conservative principles used for data selection and standard values that are specific and consistent to research results in published areas, information for national, regional and international greenhouse gas inventory, as well as the standard values from the IPCC in the same climate zone (as detailed in Annex 4)

7. Relevant parameters

7.1 Parameters require monitoring

<u>Allometric equation</u>

Parameter	y_i
Unit	ton (dry weight)
Definition	Stem volume of the ith sample tree as predicted by allometric equation
Relevant equations	Equation (1) and (2) in Annex 2 Equation (1) and (2) in Annex 3

Source of information	Predicted stem volume is calculated by inserting the relevant tree measurements (e.g. DBH and/or height) into the allometric equation
Remark	-

Volume equation

Parameter	y_i
Unit	Cubic meter
Definition	Stem volume of the ith sample tree as predicted by the volume equation or volume table
Relevant equations	Equation (1) and (2) in Annex 2 Equation (1) and (2) in Annex 3
Source of information	Predicted stem volume is calculated by inserting the relevant tree measurements (e.g. DBH and/or height) into the equation of stem volume or its table
Remark	-

7.2 Parameter required monitoring

Allometric equation

Parameter	Y_i
Unit	ton (dry weight)
Definition	Stem volume of the ith sample tree as obtained from field measurements
Relevant equations	Equation (1) and (2) in Annex 2 Equation (1) and (2) in Annex 3
Source of information	Field measurement
Measurement procedures:	Stem volume of the sample trees was calculated from the weight of fresh tree divided by the ratio of the weight of dry tree. The ratio of fresh weight to dry weight of trees varies according to tree parts such as trunk, branches, and leaves. There are alternatives to calculate the dry weight of trees as follows: Option 1 Total weight of fresh tree was divided by the ratio of the fresh weight to the total weight of dry tree, which are

	derived from academic documents such as national forest surveys, National Greenhouse Gas Accounting, and academic publications. <u>Option 2</u> Weigh each fresh section of the tree (e.g. trunk, branches, and leaves). Sample each section of the tree for drying to calculate the ratio of each tree's fresh weight to dry weight. The individual fresh weight of the tree was calculated from the individual fresh weight of the tree divided by the ratio of the individual live weight to the individual dry weight. The total dry weight of the tree is the sum of the individual dry weights of the tree.
Remark	-

<u>Volume equation</u>

Parameter	Y_i
Unit	Cubic meter
Definition	Stem volume of the ith sample tree as obtained from field measurements
Relevant equations	Equation (1) and (2) in Annex 2 Equation (1) and (2) in Annex 3
Source of information	Field measurement
Measurement procedures:	Method of measuring the stem volume either from water displacement or sectional diameter method
Remark	-

Parameter	$D_{M,i}$
Unit	Centimeter
Definition	Diameter measured from the midpoint of the stem of sample tree i
Relevant equations	Equation (2)
Source of information	Field measurement
Measurement procedures:	Measuring stem volume using sectional diameter method
Remark	-

Parameter	L_i
Unit	meter
Definition	Length of a stem from sample tree i
Relevant equations	Equation (2)
Source of information	Field measurement
Measurement procedures:	Measuring stem volume using sectional diameter method
Remark	-

8. Reference Documents

1) Demonstrating appropriateness of allometric equations for estimation of aboveground tree biomass in A/R CDM project activities (Version 01.0.0)

2) Demonstrating appropriateness of volume equations for estimation of aboveground tree biomass in A/R CDM project activities" (Version 01.0.1)

3) Guidelines on conservative choice and application of default data in estimation of the net anthropogenic GHG removals by sinks

4) 2003 Good Practice Guidance for Land Use, Land-Use Change and Forestry

5) 2006 IPCC Guidelines for National Greenhouse Gas Inventories

6) 2019 Refinement to 2006 IPCC Guidelines for National Greenhouse Gas Inventories

7) คู่มืออ้างอิงการพัฒนาโครงการลดก๊าซเรือนกระจกภาคสมัครใจตามมาตรฐานประเทศไทย สาขาป่าไม้และการเกษตร

Annex

Annex 1 Relevant Definitions

Allometric equation	Equation for estimating tree biomass which is associated with one or more variables from tree measurements such as diameter and/or height of a tree
Volume equation or volume equation table	Equation or table used for estimating stem volume which is related to one or more variables from tree measurements such as diameter and/or height of the tree
Diameter at Breath Height (DBH)	Diameter of a tree was measured at an altitude of 1.30 meters from the ground. In the case of mangroves (Rhizophora spp.), the stem growth was measured at the level above the top root by 30 cm. or according to the selected biomass equation
Aboveground biomass	Dry weight of all aboveground parts of a tree including trunks, branches, leaves, flowers and fruits including saplings and bamboo
Belowground biomass	Dry weight of underground part of a tree
Species	Types of plant grown in project area can be referred to groups/types of similar species in biomass assessment such as allometric equation selection
Biomass expansion factor (BEF)	The constant value used to convert biomass of usable stem into total tree biomass
Biomass conversion and expansion factor (BCEF)	Constant value used to convert the volume of a productive stem into a total tree biomass. The constant is directly related to BEF and the density of wood (D) as follows: $$BCEF = BEF \times D$$ In this regard, the biomass conversion/expansion coefficient used must be clearly stated that the change in stem volume used for a commodity tree, aboveground biomass, or total tree biomass.
Coefficient of determination (R^2)	A statistical value used to measure the equivalence of an equation or mathematical model. It is measured by proportion of variance in dependent variables such as tree

	biomass from independent variables e.g. diameter and/or tree height
Conservative use of an equation	The use of computational equations resulting in an acceptable estimation such as the p-value from a paired t-test in estimating tree biomass or stem volume less than 0.20

Annex 2 Calculation of p value in paired t-test

The p value calculation in paired t-test will be as follow:

1. Calculating the difference as shown in equation (1) and (2)

$$A = \sum_{i=1}^{n}(Y_i - y_i)$$ (1)

$$B = \sum_{i=1}^{n}(Y_i - y_i)^2$$ (2)

A	means	The sum of the difference between the stem volume obtained from field measurements and as calculated by the equation
B	means	The sum of square of the difference between the stem volume obtained from field measurements and as calculated by the equation
Y_i	means	<u>Allometric equation</u> Stem volume of the ith sample tree obtained from field measurement (ton of dry weight) <u>volume equation</u> Stem volume of the ith sample tree obtained from field measurements (cubic meter)
y_i	means	<u>Allometric equation</u> Stem volume of the i sample tree calculated from allometric equations (ton of dry weight) <u>Volume equation</u> Stem volume of the i sample tree calculated from the volume equation (cubic meter)

2. Calculating variance value as shown in equation (3)

$$S = \frac{n \times B - A^2}{n \times (n-1)}$$ (3)

S	means	The variance of the difference of stem volume obtained from field measurements and as calculated by the equation
A	means	The sum of the differences between the stem volume obtained from field measurements and as calculated by the equation

B means   The sum of square of the difference between the stem of trees obtained from field measurements and as calculated by the equation

n means   Number of sample trees

3. Calculating standard error as shown in equation (4)

$$E = \sqrt{\frac{S}{n}} \tag{4}$$

E means   The standard error is obtained from the difference of stem volume obtained from field measurements and as predicted by the equation

S means   The variance of the difference between stem volume from field measurements and as calculated by the equation

n means   Number of sample trees

4. Calculating t value as shown in equation (5)

$$t = \frac{A}{n \times E} \tag{5}$$

t means   Student's t-value

E means   The standard error obtained from the difference of stem volume obtained from field measurements and as calculated by the equation

n means   Number of sample trees

5. Calculating p-value

Option 1 The p-value can be found at any t-value using the Student's t-distribution table

Option 2 The p-value can be found at any t-value by using a function from the spreadsheet program as in equation (6)

$$p = TDIST(t, df, a) \tag{6}$$

p means   p-value at any t-value

df means   the number of independent value which is equivalent to $n - 1$

t means   the value of t calculated from equation (5)

a means   the calculation is defined as two-tailed distribution, so $a = 2$

Annex 3   Test in case the confidence interval of the difference between average confidence levels of 90% is not equivalent to zero

In case the confidence interval of the difference between average confidence levels of 90% is not equivalent to zero, the test can be conducted as shown in the following steps:

1. Calculating the difference as shown in equation (1) and (2)

$$A = \sum_{i=1}^{n}(Y_i - y_i) \tag{1}$$

$$B = \sum_{i=1}^{n}(Y_i - y_i)^2 \tag{2}$$

A means The sum of the differences between the stem volume obtained from field measurements and from the equation

B means The sum of square of the difference between the stem volume obtained from field measurements and from the equation

Y_i means <u>Allometric equation</u>
Stem volume of the ith sample tree obtained from field measurement (ton of dry weight)
<u>Volume equation</u>
Stem volume of the ith sample tree obtained from field measurements (cubic meter)

y_i means <u>Allometric equation</u>
Stem volume of the ith sample tree calculated from allometric equations (ton of dry weight)
<u>Volume equation</u>
Stem volume of the ith sample tree calculated from the volume equation (cubic meter)

2. Calculating variance value as shown in equation (3)

$$S = \frac{n \times B - A^2}{n \times (n-1)} \tag{3}$$

S means The variance of the difference of stem volume obtained from field measurements and as calculated by the equation

A means The sum of the differences between the stem volume obtained from field measurements and as calculated by the equation

B means   The sum of square of the difference between the stem volume obtained from field measurements and as calculated by the equation

n means   Number of sample trees

3. Calculating standard error as shown in equation (4)

$$E = \sqrt{\frac{S}{n}} \tag{4}$$

E means   The standard error is obtained from the difference of stem volume obtained from field measurements and as calculated by the equation

S means   The variance of the difference of stem volume obtained from field measurements and as calculated by the equation

n means   Number of sample trees

4. Confidence interval of the difference between average confidence level of 90% which is not equivalent to zero can be calculated using equation (5)

$$\left|\frac{A}{n}\right| > T \times E \tag{5}$$

$\left|\dfrac{A}{n}\right|$ means   The confidence interval for the difference of average confidence level of 90% which is not equivalent to zero

A means   The sum of the difference between the stem volume obtained from field measurements and as calculated by the equation

T means   Student's t-value with a number of independent values equal to n-1 at the significant level $\alpha = 0.2$ (two-tailed value)

                <u>Option 1</u> calculate T value using the table of Student's t-distribution

                <u>Option 2</u> calculate T value using a function from the spreadsheet program as shown in equation (6)

E means   The standard error is obtained from the difference of stem volume obtained from field measurements and as calculated by the equation

n means   Number of sample trees

$$T = TINV(0.2, df) \qquad (6)$$

df means number of independent value, equivalent to $n - 1$

Annex 4   Recommendations for the selection and application of standard values in calculation

Recommendations for the selection and application of default value used in calculating net greenhouse gas emissions/sequestration

1. Sources of default data

1.1 Calculating net greenhouse gas emission/sequestration, if the regulations require the use of standard values, the project developer must appropriately select to use information as required in conservative approach.

1.2 The information should be specific to the tree species. Selection criteria are listed in sequence as follow:

1.2.1 Publication domestically published must be reviewed and verified from peer-to-peer methodology. This peer-reviewed article must contain characteristics of soil, geography, and weather similar to the characteristics of project area.

1.2.2 Information used for forest resource survey or in the preparation of international greenhouse gas inventory including IPCC standard values in the same ecological zone

1.3 In the absence of such information on the specificity of tree species required in item 1.2, data must be selected at genus or family level in the same ecological zone required in conservative principles and according to clause 1.2.1-1.2.3

2. Conservative choice of default data

2.1 In case, the project area has similar standard values such as similar vegetation types in similar ecological zone, the standard values used must follow conservative principles.

2.2 In other cases, the following principles shall apply

2.2.1 Average value of the standard values must be reviewed against field data and the differences must not be more than a range of $\pm 10\%$

2.2.2 If the average value of the standard values did not follow 2.2.1, it must be assessed as follow:

- If the standard deviation exists, the mean value of standard values and the standard deviation value may be (the highest or the lowest value as seen appropriate) used according to conservative principles.

- If the standard error exists, the number of samples can be used for calculating the standard deviation and the mean value of standard values can be used according to conservative principles.
- If standard deviation does not exist but the mean value appears as an interval, a mean value must be calculated at 95% confidence level.
- If the standard data does not contain any of the above statistical value, the standard deviation must be calculated as shown in no.5.

3. Conservative definitions for the selection of standard values related to biomass calculations

The standard values used in biomass calculation must follow conservative principles, if they follow the following criteria:

3.1 To calculate net greenhouse gas emission and sequestration , when multiplying with more than 2 standard values, the standard values having highest standard deviation is considered the most appropriate as per conservative principle, while other standard values can be directly used in the calculation.

3.2 In case the standard value contains increasing value from constant value conversion, conservative principle is applied using initial standard value such as R and 1+R; when R means the root-to-shoot ratio and only R value is applied.

4. Calculating net greenhouse gas emission/sequestration by selecting a standard based on conservative principle

Net greenhouse gas emission/sequestration can be calculated by selecting standard values based on conservative principle in the following cases:

4.1 The increase in carbon sequestration occurred from non-project activities in the project area can be calculated using standard values from conservative principle. The decrease in carbon sequestration can be calculated using the mean value of related standard values.

4.2 The net greenhouse gas emission/sequestration generated from project activities can be calculated using the mean value of related standard values.

4.3   Greenhouse gas emission outside project area can be calculated using standard values from conservative principles.

5. Use of standard deviation values

When a mean value or a range of small / inadequate data set exists for standard deviation value calculation, a standard deviation value from IPCC data distribution can be used. Such data are listed below in percentage:

- Increase of aboveground volume of tree content: 50%

- Increase of aboveground biomass of tree content: 50%

- Quantity of aboveground biomass of tree content: 50%

- Biomass expansion factor (BEF) of tree content from biomass quantity baseline: between -40% (minimum value) and +100% (maximum value)

- Biomass expansion factor (BEF) of tree content from biomass quantity baseline: 10%

- Proportion of root-to-shoot biomass: 35% (perennial and sapling)

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