CLEAN DEVELOPMENT MECHANISM

CDM-ARWG38-A01

Draft A/R Methodological tool

Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities

Version 05.0 - Draft

United Nations
Framework Convention on
Climate Change

COVER NOTE

1. Procedural background

1. The CMP, in paragraph 36 of the decision 5/CMP.8 "Guidance relating to the clean development mechanism", requested the Executive Board (hereinafter referred to as the Board) of the clean development mechanism (CDM) to consider use of more cost-effective approaches in afforestation/reforestation methodologies for the estimation of baseline stocks and removals, including the use of remote sensing for monitoring. The CDM management action plan (MAP 2013) approved at the 70th meeting of the Board includes the project "204 - Enhancing cost-effectiveness of A/R CDM projects". One of the products under this project is revision of the tool “Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities” in order to make baseline estimation and monitoring of A/R CDM project activities more cost-effective.

2. A draft revision of the tool was prepared by the secretariat. A call for public inputs on the draft revision was launched which was open from 24 May to 24 June 2013. The draft document was updated on the basis of the public inputs and the inputs received from two members of the Afforestation and Reforestation Working Group (A/R WG) who were assigned to review the draft. The updated draft was considered by the A/R WG at its 38th meeting. The A/R WG agreed to recommend that the Board approve the draft revised tool as contained in annex 1 of the report of the 38th meeting of the A/R WG.

2. Purpose

3. This revision enhances cost-effectiveness of A/R CDM project activities by providing a menu of options for monitoring of carbon stocks in the above-ground and below-ground carbon pools of A/R CDM project activities.

3. Key issues and proposed solutions

4. Specifically, the revision provides for:

    (a) Added options of using double sampling and simplified method of ‘no-decrease’ for monitoring of carbon stocks;

    (b) Possibility for use of remote sensing data (e.g. the Normalized Difference Vegetation Index, or NDVI) in monitoring;

    (c) Possibility of applying different estimation methods in different strata and across different verifications;

    (d) A comprehensive approach for uncertainty management.

5. The structure of the tool was improved while some sections of the tool were moved to the appendices of the tool in order to improve readability.

4. Impacts

6. The revision of the tool will provide the project participants a number of options from which they can choose those options which are more cost-effective in the specific circumstances of their project activity.

7. The revision will not have any adverse impact on A/R CDM project activities that are already registered.

5. Subsequent work and timelines

8. If approved by the Board, the revised tool will become effective from the date of publication on the UNFCCC website following the approval of the Board, and the earlier version of the tool shall remain valid for a period of 240 days.

6. Recommendations to the Board

9. The A/R WG recommends that the draft revision of the tool be approved by the Board.

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1. Introduction

1. This tool provides step-by-step methods for estimation of carbon stock in living biomass of trees and shrubs. For ex-ante (projected) estimation of tree biomass it applies tree growth and stand development models. For ex-post (actual) estimation of tree biomass it uses data from measurements conducted in sample plots. Remote sensing data may also be used in conjunction with data from measurements conducted in sample plots. Biomass of shrubs is estimated from shrub crown cover.

2. Scope, applicability, and entry into force

2.1. Scope

2. This tool can be used for estimation of carbon stock and change in carbon stock in living biomass of trees and shrubs in an afforestation and reforestation (A/R) clean development mechanism (CDM) project activity. The tool is applicable for:

   (a) Estimation of carbon stock and change in carbon stock in living biomass of trees and shrubs in baseline;

   (b) Ex-ante estimation (projection) of carbon stock and change in carbon stock in living biomass of trees and shrubs in project;

   (c) Ex-post estimation of carbon stock and change in carbon stock in trees and shrubs for monitoring of project activities.

2.2. Applicability

3. This tool has no internal applicability conditions.

Entry into force

4. The date of entry into force of the revision is the date of the publication of the EB 75 meeting report on 4 October 2013.

3. Definitions and notation

5. The definitions contained in the Glossary of CDM terms shall apply.

6. For the purpose of this tool, the following definitions apply:

   (a) **Uncertainty -** is in the mean value of an estimated parameter equal to the estimated standard error of the mean expanded at 90 per cent confidence level divided by the mean value, expressed as percentage;

   Example: The mean value of above-ground tree biomass per hectare is estimated as 45.328 t d.m. ha^{-1} from a sample of size 34. Sample standard deviation was 12.776 t d.m. ha^{-1}. The estimated standard error of the mean (SEM) is $12.776/\sqrt{34}$ = 2.191 t d.m. ha^{-1}. The SEM expanded at 90 per cent confidence level is therefore = 2.191 x $t_{(0.1,33)}$ = 2.191 x 1.692 = 3.707 t d.m. ha^{-1}. This implies that the estimated mean has an uncertainty of (3.707/45.328) ×100 = 8.18 per cent.

Note. In this tool only sampling uncertainty is assessed and controlled. Uncertainty in values obtained from direct measurement (e.g. measured diameter of a tree) or values derived from models (e.g. biomass of a tree derived from its diameter using an allometric equation) is not quantified. This type of uncertainty should be managed through application of appropriate quality assurance and quality control (QA/QC) methods, as explained in the parameter description tables in section 12.

(b) **Species -** can also refer to a species group when a species-specific biometric parameter (e.g. biomass expansion factor), or a model (e.g. allometric equation), is demonstrated to be applicable to more than one species;

(c) **Tree biomass -** refers to above-ground and below-ground living biomass of trees;

(d) **Shrub biomass -** refers to above-ground and below-ground living biomass of shrubs;

(e) **Plot biomass -** refers to tree biomass per hectare in a plot;

(f) **Measurement of a sample plot -** refers to the measurement of one or more dimensions (e.g. diameter) of the trees in a sample plot, or measurement of a plot parameter (e.g. basal area per hectare), and conversion of the measured tree dimensions, or the measured plot parameter into plot biomass by using one of the methods provided in appendix 1;

(g) **Conservative value of a parameter -** refers to the value which, when used in calculations, is more likely to result in underestimation rather than overestimation of the net anthropogenic GHG removals by sinks;

7. For reasons of consistency and readability, this tool uses the following conventions in naming of variables and parameters:

(a) Symbols for unit quantities (e.g. per hectare quantities) use lower case letters (e.g. b_{FOREST}), whereas symbols for total quantities use uppercase letters (e.g. B_{TREE});

(b) Subscripts used for qualifying a variable or a parameter appear in upper case letters (e.g. $C_{SHRUB\_PROJECT}$), whereas subscripts used for denoting indices appear in lower case letters (e.g. $C_{SHRUB\_PROJECT,i}$).

7. This tool uses the following units in their abbreviated form:

(a) Tonne dry matter is abbreviated as t d.m., and tonne dry matter per hectare is abbreviated as t d.m. ha^{-1};

(b) Tonne carbon dioxide equivalent is abbreviated as t CO_2e.

4. Parameters determined by the tool

8. This tool provides procedures to determine the parameters listed in table 1.

Table 1. Parameters determined by the tool

Parameter	Unit	Description
$C_{TREE,t}$	t CO_2e	Carbon stock in tree biomass within the project boundary at a given point of time in year *t*
$\Delta C_{TREE,t}$	t CO_2e	Change in carbon stock in tree biomass within the project boundary in year *t*
$C_{SHRUB,t}$	t CO_2e	Carbon stock in shrub biomass within the project boundary at a given point of time in year *t*
$\Delta C_{SHRUB,t}$	t CO_2e	Change in carbon stock in shrub biomass within the project boundary in year *t*

9. While applying this tool in an approved A/R CDM methodology, the following corresponding notations should be used:

(a) In the baseline scenario:

$C_{TREE\_BSL,t}$ for $C_{TREE,t}$ and $C_{SHRUB\_BSL,t}$ for $C_{SHRUB,t}$

$\Delta C_{TREE\_BSL,t}$ for $\Delta C_{TREE,t}$ and $\Delta C_{SHRUB\_BSL,t}$ for $\Delta C_{SHRUB,t}$

(b) In the project scenario:

$C_{TREE\_PROJ,t}$ for $C_{TREE,t}$ and $C_{SHRUB\_PROJ,t}$ for $C_{SHRUB,t}$

$\Delta C_{TREE\_PROJ,t}$ for $\Delta C_{TREE,t}$ and $\Delta C_{SHRUB\_PROJ,t}$ for $\Delta C_{SHRUB,t}$

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

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

(a) The pre-project trees are neither harvested, nor cleared, nor removed throughout the crediting period of the project activity;

(b) The pre-project trees do not suffer mortality because of competition from trees planted in the project, or damage because of implementation of the project activity, at any time during the crediting period of the project activity;

(c) 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.

11. Changes in carbon stocks in trees and shrubs 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 the following indicators apply:

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

(b) Presence of gully, sheet or rill erosion; or landslides, or other forms of mass-movement erosion;

(c) Presence of plant species locally known to be indicators of infertile land;

(d) Land comprises of bare sand dunes, or other bare lands;

(e) Land contains contaminated soils, mine spoils, or highly alkaline or saline soils;

(f) 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;

(g) Conditions (a), (b) and (c) under paragraph 10 apply.

12. For the purpose of ex-ante estimation of carbon stock and change in carbon stock in the project scenario, change in carbon stock of shrubs may be estimated as zero.

6. Estimating change in carbon stock in trees between two points of time

13. Change in carbon stock in trees between two points of time is estimated by using one of the following methods or a combination thereof:

(a) Difference of two independent stock estimations;

(b) Direct estimation of change by re-measurement of sample plots;

(c) Estimation by proportionate crown cover;

(d) Demonstration of “no-decrease”.

Difference of two independent stock estimations

14. Under this method, change in carbon stock in trees is estimated as the difference between two successive and independent carbon stock estimations.

Note. This is method is efficient 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).

15. Under this method, the change in carbon stock in trees and the associated uncertainty are estimated as follows:

$$\Delta C_{TREE} = C_{TREE,t_2} - C_{TREE,t_1}$$ Equation (1)

$$u_{\Delta C} = \frac{\sqrt{\left(u_1 \times C_{TREE,t_1}\right)^2 + \left(u_2 \times C_{TREE,t_2}\right)^2}}{|\Delta C_{TREE}|}$$ Equation (2)

Where:

ΔC_{TREE}	=	Change in carbon stock in trees during the period between two points of time t_1 and t_2; t CO_2e
C_{TREE,t_1}	=	Carbon stock in trees as estimated at time t_1; t CO_2e Note 1. At the first verification C_{TREE,t_1} is set equal to the carbon stock in the pre-project tree biomass ($i.e.$ $C_{TREE,t_1} = C_{TREE\_BSL}$). However, this may be set equal to zero, if all of the conditions specified under paragraph 10 are met. Note 2. Even if C_{TREE,t_1} was made conservative at the time of previous verification, it is the estimated (undiscounted) value of C_{TREE,t_1} that is used here.
C_{TREE,t_2}	=	Carbon stock in trees as estimated at time t_2; t CO_2e
$u_{\Delta C}$	=	Uncertainty in ΔC_{TREE}
u_1, u_2	=	Uncertainties in C_{TREE,t_1} and C_{TREE,t_2} respectively

16. Carbon stock in trees at a point of time is estimated by using one of the applicable methods provided in section 8.

17. If $u_{\Delta C}$ estimated from Equation (2) is greater than 10 per cent, ΔC_{TREE} is made conservative by applying uncertainty discount according to the procedure provided in appendix 2.

Direct estimation of change by re-measurement of sample plots

18. This method is applicable only in ex-post estimation of change in carbon stock in trees for monitoring of project activities. Under this method, the same sample plots are measured on two successive occasions and the plot-level change in biomass is obtained by subtracting the plot biomass on the first occasion from the plot biomass on the second occasion.

    Note. This is method is efficient when there is a significant correlation between the plot biomass values on the two occasions (e.g. when there has been no harvest or disturbance in a stratum and therefore no significant spatial re-distribution of biomass has occurred in the stratum after the first estimation).

19. Under this method, the change in carbon stock and the associated uncertainty are estimated as follows:

$$\Delta C_{TREE} = \frac{44}{12} \times CF_{TREE} \times \Delta B_{TREE} \qquad \text{Equation (3)}$$

$$\Delta B_{TREE} = A \times \Delta b_{TREE} \qquad \text{Equation (4)}$$

$$\Delta b_{TREE} = \sum_{i=1}^{M} w_i \times \Delta b_{TREE,i}$$ Equation (5)

$$u_{\Delta C} = \frac{t_{VAL} \times \sqrt{\sum_{i=1}^{M} w_i^2 \times \frac{s_{\Delta,i}^2}{n_i}}}{|\Delta b_{TREE}|}$$ Equation (6)

Where:

ΔC_{TREE}	=	Change in carbon stock in trees between two successive measurements; t CO_2e
CF_{TREE}	=	Carbon fraction of tree biomass; t C (t d.m.)$^{-1}$ A default value of 0.47 is used unless transparent and verifiable information can be provided to justify a different value.
ΔB_{TREE}	=	Change in tree biomass within the biomass estimation strata; t d.m.
A	=	Sum of areas of the biomass estimation strata; ha
Δb_{TREE}	=	Mean change in tree biomass per hectare within the biomass estimation strata; t d.m. ha^{-1}
w_i	=	Ratio of the area of stratum *i* to the sum of areas of biomass estimation strata (i.e. $w_i = A_i/A$); dimensionless
$\Delta b_{TREE,i}$	=	Mean change in carbon stock per hectare in tree biomass in stratum *i*; t d.m. ha^{-1}
$u_{\Delta C}$	=	Uncertainty in ΔC_{TREE}
t_{VAL}	=	Two-sided Student's *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 strata
$s_{\Delta,i}^2$	=	Variance of mean change in tree biomass per hectare in stratum *i*; (t d.m. ha^{-1})^2
n_i	=	Number of sample plots, in stratum *i*, in which tree biomass was re-measured

20. Mean change in tree biomass per hectare in a stratum and the associated variance are estimated as follows:

$$\Delta b_{TREE,i} = \frac{\sum_{p=1}^{n_i} \Delta b_{TREE,p,i}}{n_i}$$ Equation (7)

$$s_{\Delta,i}^2 = \frac{n_i \times \sum_{p=1}^{n_i} \Delta b_{TREE,p,i}^2 - \left(\sum_{p=1}^{n_i} \Delta b_{TREE,p,i}\right)^2}{n_i \times (n_i - 1)}$$ Equation (8)

Where:

$\Delta b_{TREE,i}$ = Mean change in tree biomass per hectare in stratum *i*; t d.m. ha^{-1}

$\Delta b_{TREE,p,i}$ = Change in tree biomass per hectare in plot *p* in stratum *i*; t d.m. ha^{-1}

$s_{\Delta,i}^2$ = Variance of mean change in tree biomass per hectare in stratum *i*; (t d.m. $ha^{-1})^2$

n_i = Number of sample plots, in stratum *i*, in which tree biomass was re-measured

21. If $u_{\Delta C}$ estimated from Equation (6) is greater than 10 per cent, ΔC_{TREE} is made conservative by applying uncertainty discount according to the procedure provided in appendix 2.

22. Tree biomass per hectare in a sample plot is estimated by applying one of the plot measurement methods provided in appendix 1.

6.1. Estimation by proportionate crown cover

23. This method is applicable only in ex-ante estimation of change in carbon stock in trees in the baseline where the mean pre-project tree crown cover is less than 20 per cent of the threshold tree crown cover reported by the host Party under paragraph 8 of the annex to decision 5/CMP.1

<u>Example.</u> The host Party has reported a threshold tree crown cover of 30 per cent to define ‘forest’ for the purposes of the CDM. The method of estimation by proportionate crown cover is applicable only if the mean pre-project tree crown cover is less than 20 per cent of 30 per cent (i.e. less than 6 per cent).

24. Under this method, the change in carbon stock in trees in the baseline is estimated as follows:

$$\Delta C_{TREE\_BSL} = \sum_{i=1}^{M} \Delta C_{TREE\_BSL,i}$$ Equation (9)

$$\Delta C_{TREE\_BSL,i} = \frac{44}{12} \times CF_{TREE} \times \Delta b_{FOREST} \times (1 + R_{TREE}) \times CC_{TREE\_BSL,i} \times A_i$$ Equation (10)

Where:

ΔC_{TREE_BSL} = Mean annual change in carbon stock in trees in the baseline; t CO_2e yr^{-1}

$\Delta C_{TREE\_BSL,i}$ = Mean annual change in carbon stock in trees in the baseline, in baseline stratum *i*; t CO_2e yr^{-1}

CF_{TREE}	=	Carbon fraction of tree biomass; t C (t.d.m.)$^{-1}$. A default value of 0.47 t C (t.d.m.)$^{-1}$ is used unless transparent and verifiable information can be provided to justify a different value.
Δb_{FOREST}	=	Default mean annual increment of above-ground biomass in forest in the region or country where the A/R CDM project activity is located; t d.m. ha^{-1} yr^{-1}. Values of Δb_{FOREST} are taken from Table 3A.1.5 of the *IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC GPG-LULUCF 2003) unless transparent and verifiable information can be provided to justify different values. Note. Tree biomass may reach a steady state in which biomass growth becomes zero or insignificant, either because of biological maturity of trees or because the rate of anthropogenic biomass extraction from the area is equal to the rate of biomass growth. Therefore, this parameter should be taken to be zero after the year in which tree biomass in the baseline reaches a steady state. The year in which tree biomass in the baseline reaches a steady-state is taken to be the 20th year from the start of the CDM project activity, unless transparent and verifiable information can be provided to justify a different year.
R_{TREE}	=	Root-shoot ratio for the trees in the baseline; dimensionless. A default value of 0.25 is used unless transparent and verifiable information can be provided to justify a different value.
$CC_{TREE\_BSL,i}$	=	Crown cover of trees in the baseline, in baseline stratum *i*, at the start of the A/R CDM project activity, expressed as a fraction (e.g. 10 per cent crown cover implies $CC_{TREE\_BSL,i}$ = 0.10); dimensionless
A_i	=	Area of baseline stratum *i*, delineated on the basis of tree crown cover at the start of the A/R CDM project activity; ha

6.2. Demonstration of “no-decrease”

25. This method is applicable only in ex-post estimation of change in carbon stock in trees for monitoring of project activities. Project participants may, at the time of a verification, demonstrate that tree biomass in one or more strata has not decreased relative to the tree biomass at the time of the previous verification, by proving that:

(a) No harvest has occurred in the stratum since the previous verification;

(b) The stratum was not affected by any disturbance (e.g. pest, fire) that would decrease the carbon stock in trees;

(c) Remote sensing data or inventory data, including participatory inventory or participatory photo-mapping data, demonstrate that tree crown cover in the stratum has not decreased since the previous verification.

26. Where all the three conditions above are demonstrated to have been met in a stratum, the change in carbon stock in trees in that stratum since the previous verification may be conservatively estimated as zero.

Note. This method is efficient when project participants are required to submit a verification and certification report at a point of time when the biomass increase in the project since the previous verification may not be large enough to justify the cost of conducting an inventory (e.g. when periodic verification and certification is required to re-validate lCERs already issued and significant number of new lCERs is not expected).

7. Estimating change in carbon stock in trees in a year

27. Change in carbon stock in trees in a year (annual change) between two successive verifications is estimated on the assumption of linear change.

28. Change in carbon stock in trees in a year is estimated as follows:

$$\Delta C_{TREE,t} = \frac{C_{TREE,t_2} - C_{TREE,t_1}}{T} \times 1\ year$$ Equation (11)

Where:

$\Delta C_{TREE,t}$	=	Change in carbon stock in trees within the project boundary in year *t*; t CO_2e
C_{TREE,t_2}	=	Carbon stock in trees within the project boundary at time t_2; t CO_2e. Note. Where estimation of carbon stock in tree biomass at time t_2 is carried out by applying different methods in different strata, C_{TREE,t_2} is set equal to the sum of carbon stocks in all the strata in which the project area is divided.
C_{TREE,t_1}	=	Carbon stock in trees within the project boundary at time t_1; t CO_2e. Note. Where estimation of carbon stock in tree biomass at time t_1 is carried out by applying different methods in different strata, C_{TREE,t_1} is set equal to the sum of carbon stocks in all the strata in which the project area is divided.
T	=	Time elapsed between two successive estimations ($T = t_2 - t_1$); yr. Note 1. Value of *T* does not have to be a whole number (e.g. an interval of 4 years and 5 months implies T = 4.417 yr). Note 2. Estimation of change in carbon stock in trees by proportionate crown cover (*see* section 6.3) results in an annual change estimate and hence Equation (11) does not apply under this method.

8. Estimating carbon stock in trees at a point of time

29. Carbon stock in trees at a point of time is estimated by using one of the following methods or a combination thereof:

(a) Estimation by measurement of sample plots;

(b) Estimation by modelling of tree growth and stand development;

(c) Estimation by proportionate crown cover;

(d) Updating the previous stock by independent measurement of change.

30. When estimation is carried out by methods (a), (c) or (d) above, the date of last measurement of sample plot, or estimation of crown cover, is considered to be the date of estimation of carbon stock, even if the full process of measurement extends over a period of time.

31. Where estimation of carbon stock in trees at a given point of time in year t is carried out by applying different methods in different strata, the value of $C_{TREE,t}$ is set equal to the sum of carbon stocks in all the strata in which the project area was divided.

8.1. Estimation by measurement of sample plots

32. Under this method, carbon stock in trees is estimated on the basis of measurements of sample plots. Sample plots are installed in one or more strata. Two sampling designs are available:

(a) Stratified random sampling;

(b) Double sampling.

8.1.1. Stratified random sampling

33. Under this method, random sample plots are installed in the strata (e.g. systematic sampling with a random start) and measured.

Note. This method is more efficient when the sample plots are optimally allocated to the strata keeping in view the expected mean tree biomass per hectare and its variability in the strata. Number of sample plots and their allocation to strata may be estimated by using the A/R methodological tool “Calculation of the number of sample plots for measurements within A/R CDM project activities”.

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.

34. Mean carbon stock in trees within the tree biomass estimation strata and the associated uncertainty are estimated as follows (all time-dependent quantities relate to the time of measurement):

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

$$B_{TREE} = A \times b_{TREE}$$ Equation (13)

$$b_{TREE} = \sum_{i=1}^{M} w_i \times b_{TREE,i}$$ Equation (14)

$$u_C = \frac{t_{VAL} \times \sqrt{\sum_{i=1}^{M} w_i^2 \times \frac{s_i^2}{n_i}}}{b_{TREE}}$$ Equation (15)

Where:

C_{TREE}	=	Carbon stock in trees in the tree biomass estimation strata; t CO_2e
CF_{TREE}	=	Carbon fraction of tree biomass; t C (t d.m.)$^{-1}$. A default value of 0.47 is used unless transparent and verifiable information can be provided to justify a different value.
B_{TREE}	=	Tree biomass in the tree biomass estimation strata; t d.m.
A	=	Sum of areas of the tree biomass estimation strata; ha
b_{TREE}	=	Mean tree biomass per hectare in the tree biomass estimation strata; t d.m. ha^{-1}
w_i	=	Ratio of the area of stratum *i* to the sum of areas of tree biomass estimation strata (i.e. $w_i = A_i/A$); dimensionless
$b_{TREE,i}$	=	Mean tree biomass per hectare in stratum *i*; t d.m. ha^{-1}
u_C	=	Uncertainty in C_{TREE}
t_{VAL}	=	Two-sided Student's *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 strata
s_i^2	=	Variance of tree biomass per hectare across all sample plots in stratum *i*; (t d.m. ha^{-1})^2
n_i	=	Number of sample plots in stratum *i*.

35. Mean tree biomass per hectare in a stratum and the associated variance are estimated as follows:

$$b_{TREE,i} = \frac{\sum_{p=1}^{n_i} b_{TREE,p,i}}{n_i}$$ Equation (16)

$$s_i^2 = \frac{n_i \times \sum_{p=1}^{n_i} b_{TREE,p,i}^2 - \left(\sum_{p=1}^{n_i} b_{TREE,p,i}\right)^2}{n_i \times (n_i - 1)}$$ Equation (17)

Where:

$b_{TREE,i}$	=	Mean tree biomass per hectare in stratum *i*; t d.m. ha^{-1}
$b_{TREE,p,i}$	=	Tree biomass per hectare in plot *p* of stratum *i*; t d.m. ha^{-1}
s_i^2	=	Variance of mean tree biomass per hectare in stratum *i*; (t d.m. $ha^{-1})^2$
n_i	=	Number of sample plots in stratum *i*.

36. If u_C estimated from Equation (15) is greater than 10 per cent, C_{TREE} is made conservative by applying uncertainty discount according to the procedure provided in appendix 2.

37. Tree biomass per hectare in a plot is estimated by using one of the plot measurement methods provided in appendix 1.

8.1.2. Double sampling

38. 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.

39. This method is applicable only if there is a linear relationship between the plot biomass values and the plot values of the secondary variable (i.e. the best-fit curve is a straight line) within the range of the values.

Note. 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 double sampling it would have been necessary to conduct plot biomass measurement in 200 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.

40. Equations (12) to (15) also apply in this method for aggregating the mean and its variance over the strata. However, for each stratum in which double sampling is applied, the following equations apply instead of Equations (16) and (17):

$$b_{TREE,i} = \frac{\sum_{p=1}^{n_i} b_{TREE,p,i}}{n_i} + \beta \times (\overline{x'} - \bar{x})$$ Equation (18)

$$s_i^2 = \frac{n_i \times \sum_{p=1}^{n_i} b_{TREE,p,i}^2 - \left(\sum_{p=1}^{n_i} b_{TREE,p,i}\right)^2}{n_i \times (n_i - 1)} \times (1 - (1 - \alpha) \times \rho^2)$$ Equation (19)

Where:

$b_{TREE,i}$	=	Mean tree biomass per hectare in stratum *i*; t d.m. ha^{-1}
$b_{TREE,p,i}$	=	Tree biomass per hectare in plot *p* of stratum *i*; t d.m. ha^{-1}
n_i	=	Number of sample plots in the sub-sample
β	=	Slope of the regression line of tree biomass per hectare in a sample plot against the secondary variable value of the plot
$\overline{x'}$	=	Mean value of the secondary variable across all the sample plots
$\bar{x}$	=	Mean value of the secondary variable across the sub-sample of sample plots in which tree biomass is also measured
s_i^2	=	Variance of mean tree biomass per hectare in stratum *i*; (t d.m. $ha^{-1})^2$
α	=	Ratio of number of sample plots in the sub-sample to the number of sample plots in the sample (α <1)
ρ	=	Coefficient of correlation between the secondary variable and the tree biomass per hectare in a sample plot, estimated across all the sample plots in the sub-sample

41. The slope of the regression β and the coefficient of correlation ρ are calculated as explained in appendix 3.

42. Tree biomass per hectare in a sample plot is estimated by using one of the plot measurement methods provided in appendix 1.

43. If u_C estimated from Equation (15) is greater than 10 per cent, C_{TREE} is made conservative by applying uncertainty discount according to the procedure provided in appendix 2.

8.2. Estimation by modelling of tree growth and stand development

44. This method is used for ex-ante estimation (projection) of carbon stock in tree biomass. Under this method existing data are used in combination with tree growth models to predict the growth of trees and the development of the tree stand over time.

45. 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).

46. 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.

47. Ex-ante estimation (projection) of carbon stock in tree biomass is not subjected to uncertainty control, although the project participants should use the best available data and models that apply to the project site and the tree species.

8.3. Estimation by proportionate crown cover

48. This method is applicable only for estimation of the pre-project carbon stock in tree biomass in the baseline where the mean pre-project tree crown cover is less than 20 per cent of the threshold tree crown cover reported by the host Party under paragraph 8 of the annex to decision 5/CMP.1.

Example. The host Party has reported a threshold tree crown cover of 30 per cent for defining ‘forest’ for the purposes of the CDM. This method is applicable only if the mean pre-project tree crown cover is less than 20 per cent of 30 per cent (i.e. less than 6 per cent).

49. Carbon stock in trees is estimated on the basis of tree crown cover at the time of the start of the project (the pre-project tree crown cover). The area within the project boundary is stratified by pre-project tree crown cover.

50. Under this method, carbon stock in tree biomass is estimated as follows:

$$C_{TREE\_BSL} = \sum_{i=1}^{M} C_{TREE\_BSL,i}$$ Equation (20)

$$C_{TREE\_BSL,i} = \frac{44}{12} \times CF_{TREE} \times b_{FOREST} \times (1 + R_{TREE}) \times CC_{TREE\_BSL,i} \times A_i$$ Equation (21)

Where

C_{TREE_BSL}	=	Carbon stock in pre-project tree biomass; t CO_2e
$C_{TREE\_BSL,i}$	=	Carbon stock in pre-project tree biomass in stratum *i*; t CO_2e
CF_{TREE}	=	Carbon fraction of tree biomass; t C $(t.d.m.)^{-1}$. A default value of 0.47 t C $(t.d.m.)^{-1}$ is used.
b_{FOREST}	=	Mean above-ground biomass in forest in the region or country where the A/R CDM project is located; t d.m. ha^{-1} Values from Table 3A.1.4 of IPCC GPG-LULUCF 2003 are used unless transparent and verifiable information can be provided to justify different values.
R_{TREE}	=	Root-shoot ratio for trees in the baseline; dimensionless. A default value of 0.25 is used unless transparent and verifiable information can be provided to justify a different value.
$CC_{TREE\_BSL,i}$	=	Crown cover of trees in baseline stratum *i*, at the start of the A/R CDM project activity, expressed as a fraction (e.g. 10 per cent crown cover implies $CC_{TREE\_BSL,i}$ = 0.10); dimensionless
A_i	=	Area of baseline stratum *i*, delineated on the basis of tree crown cover at the start of the A/R CDM project activity; ha

8.4. Updating previous stock by direct estimation of change

51. Under this method, the new carbon stock in trees is obtained by adding the change in carbon stock in trees estimated by re-measurement of plots (*see* section 6.2) to the carbon stock estimated at the previous verification.

Note. This method is efficient when the number of tCERs are to be estimated and the method of direct estimation of change in carbon stock by re-measurement of sample plots is efficient. Since tCERs are based on total carbon stock, the carbon stock estimated at the previous verification must be updated by adding the change in carbon stock to arrive at the carbon stock at the second verification.

52. Under this method, carbon stock in trees in a stratum and the associated uncertainty are estimated as follows:

$$C_{TREE,t_2} = C_{TREE,t_1} + \Delta C_{TREE} \quad \text{Equation (22)}$$

$$u_2 = \frac{\sqrt{\left(u_1 \times C_{TREE,t_1}\right)^2 + (u_{\Delta C} \times \Delta C_{TREE})^2}}{C_{TREE,t_2}} \quad \text{Equation (23)}$$

Where:

C_{TREE,t_2}	=	Carbon stock in trees at time t_2; t CO_2e

C_{TREE,t_1}	=	Carbon stock in trees as estimated at time t_1; t CO_2e Note. Even if C_{TREE,t_1} was made conservative at the time of the previous verification, it is the estimated (undiscounted) value of C_{TREE,t_1} that is used here.
ΔC_{TREE}	=	Change in carbon stock in trees during the period between times t_1 and t_2; t CO_2e
$u_{\Delta C}$	=	Uncertainty in ΔC_{TREE}
u_2, u_1	=	Uncertainties in C_{TREE,t_2} and C_{TREE,t_1} respectively

53. If u_2 estimated from Equation (23) is greater than 10 per cent, C_{TREE,t_2} is made conservative by applying uncertainty discount according to the procedure provided in appendix 2.

9. Estimating change in carbon stock in shrubs between two points of time

54. Change in carbon stock in shrubs between two points of time is estimated as follows:

$$\Delta C_{SHRUB} = C_{SHRUB,t_2} - C_{SHRUB,t_1}$$ Equation (24)

Where:

ΔC_{SHRUB}	=	Change in carbon stock in shrub biomass during the period between times t_1 and t_2; t CO_2-e
C_{SHRUB,t_2}	=	Carbon stock in shrub biomass at time t_2; t CO_2-e
C_{SHRUB,t_1}	=	Carbon stock in shrub biomass at time t_1; t CO_2-e

55. Carbon stock in shrub biomass at a point of time is estimated by using the method provided in section 10.

56. Where, by applying *mutatis mutandis* the “no decrease” method provided under section 6.4 to shrubs, it can be shown that there has been no decrease in carbon stock in shrubs in one or more strata since the previous verification, the value of ΔC_{SHRUB} for those strata can be estimated as zero.

10. Estimating change in carbon stock in shrubs in a year

57. Change in carbon stock in shrubs in a year (annual change) between two successive verifications is estimated on the assumption of linear change.

58. Change in carbon stock in shrubs in a year is estimated as follows:

$$\Delta C_{SHRUB,t} = \frac{C_{SHRUB,t_2} - C_{SHRUB,t_1}}{T} \times 1\ year$$ Equation (25)

Where:

$\Delta C_{SHRUB,t}$	=	Change in carbon stock in shrubs within the project boundary in year *t* between times t_1 and t_2; t CO_2-e
C_{SHRUB,t_2}	=	Carbon stock in shrubs within the project boundary at time t_2; t CO_2e
C_{SHRUB,t_1}	=	Carbon stock in shrubs within the project boundary at time t_1; t CO_2e
T	=	Time elapsed between two successive estimations ($T=t_2 - t_1$); yr Note. Value of *T* does not have to be a whole number (e.g. an interval of 4 years and 5 months implies T = 4.417 yr).

11. Estimating carbon stock in shrubs at a point of time

59. Carbon stock in shrubs at a point of time is estimated on the basis of shrub crown cover. The area within the project boundary is stratified by shrub crown cover. Those areas where the shrub crown cover is less than 5 per cent are treated as a single stratum and the shrub biomass in this stratum is estimated as zero.

60. For the strata with a shrub crown cover of greater than 5 per cent, carbon stock in shrubs is estimated as follows:

$$C_{SHRUB,t} = \frac{44}{12} \times CF_s \times (1 + R_s) \times \sum_i A_{SHRUB,i} \times b_{SHRUB,i} \qquad \text{Equation (26)}$$

$$b_{SHRUB,i} = BDR_{SF} \times b_{FOREST} \times CC_{SHRUB,i} \qquad \text{Equation (27)}$$

Where:

$C_{SHRUB,t}$	=	Carbon stock in shrubs within the project boundary at a given point of time in year *t*; t CO_2-e
CF_s	=	Carbon fraction of shrub biomass; t C $(t.d.m.)^{-1}$. A default value of 0.47 is used unless transparent and verifiable information can be provided to justify a different value.
R_s	=	Root-shoot ratio for shrubs; dimensionless. The default value of 0.40 is used unless transparent and verifiable information can be provided to justify a different value.
$A_{SHRUB,i}$	=	Area of shrub biomass estimation stratum *i*; ha
$b_{SHRUB,i}$	=	Shrub biomass per hectare in shrub biomass estimation stratum *i*; t d.m. ha^{-1}

BDR_{SF}	=	Ratio of shrub biomass per hectare in land having a shrub crown cover of 1.0 (i.e. 100 per cent) and the default above-ground biomass content per hectare in forest in the region/country where the A/R CDM project activity is located; dimensionless. A default value of 0.10 should be used unless transparent and verifiable information can be provided to justify a different value.
b_{FOREST}	=	Default above-ground biomass content in forest in the region/country where the A/R CDM project activity is located; t d.m. ha^{-1}. Values from Table 3A.1.4 of IPCC GPG-LULUCF 2003 are used unless transparent and verifiable information can be provided to justify different values.
$CC_{SHRUB,i}$	=	Crown cover of shrubs in shrub biomass estimation stratum *i* at the time of estimation, expressed as a fraction (e.g. 10 per cent crown cover implies $CC_{SHRUB,i}$ = 0.10); dimensionless

12. Data and parameters used in the tool

61. This section describes the requirements for the data and parameters used in this tool. The requirements contained in the following data description tables should be treated as an integral part of the tool.

12.1. Data and parameters not monitored

62. The values, sources, and requirements for data and parameters which are not subject to monitoring are provided in the text of the tool along with the equations in which these are used.

12.2. Data and parameters monitored.

63. The requirements for data and parameters subject to monitoring are provided in the tables below.

Data / Parameter table 1. Area of land

Data / Parameter:	$\mathbf{A_{PLOT,i}}$, $\mathbf{A_{SHRUB,i}}$, $\mathbf{A_i}$
Data unit:	Ha
Description:	Area of a sample plot; area of a stratum
Source of data:	Field measurement
Measurement procedures (if any):	Standard operating procedures (SOPs) prescribed under national forest inventory are applied. In the absence of these, SOPs from published handbooks, or from the IPCC GPG LULUCF 2003, are applied
Monitoring frequency:	At every verification

QA/QC procedures:	Quality control/quality assurance (QA/QC) procedures prescribed under national forest inventory are applied. In the absence of these, QA/QC procedures from published handbooks, or from the IPCC GPG LULUCF 2003, are applied

Data / Parameter table 2. Shrub crown cover

Data / Parameter:	$\mathbf{CC_{SHRUB,i}}$
Data unit:	Dimensionless
Description:	Crown cover of shrubs in shrub biomass stratum *i*
Source of data:	Field measurement
Measurement procedures (if any):	Considering that the biomass in shrubs is smaller than the biomass in trees, a simplified method of measurement may be used for estimating shrub crown cover. Ocular estimation of crown cover may be carried out or any other method such as the line transect method or the relascope method may be applied
Monitoring frequency:	At every verification
QA/QC procedures:	Quality control/quality assurance (QA/QC) procedures prescribed under national forest inventory are applied. In the absence of these, QA/QC procedures from published handbooks, or from the IPCC GPG LULUCF 2003, are applied
Comment:	When land is subjected to periodic cycles (e.g. slash-and-burn, or clearing-regrowing cycles) so that the shrub crown cover oscillates between a minimum and maximum values in the baseline, an average shrub crown cover equal to 0.5 is used unless transparent and verifiable information can be provided to justify a different value

Data / Parameter table 3. Tree crown cover

Data / Parameter:	$\mathbf{CC_{TREE\_BSL,i}}$
Data unit:	Dimensionless
Description:	Crown cover of trees in the baseline stratum *i*
Source of data:	Field measurement
Measurement procedures (if any):	Considering that the biomass in trees in the baseline is smaller compared to the biomass in trees in the project, a simplified method of measurement may be used for estimating tree crown cover. Ocular estimation of tree crown cover may be carried out or any other method such as the line transect method or the relascope method may be applied
Monitoring frequency:	Measured only once (at the beginning of the project)
QA/QC procedures:	Quality control/quality assurance (QA/QC) procedures prescribed under national forest inventory are applied. In the absence of these, QA/QC procedures from published handbooks, or from the IPCC GPG LULUCF 2003, are applied
Comment:	When land is subjected to periodic cycles (e.g. slash-and-burn, or clearing-regrowing cycles) so that the tree crown cover oscillates between a minimum and maximum values in the baseline, the value of this parameter should be set equal to half the maximum tree crown cover that would be achieved under the cycle

Appendix 1. Methods of plot biomass measurement

1. This appendix provides methods for measurement of tree biomass per hectare in a sample plot (the plot biomass value). Plot biomass values are estimated from direct or indirect measurements conducted on trees in the sample plot. Table 1 presents the type of measurements and the methods for converting these measurements into tree biomass.

Table 1. Plot measurements and their conversion to tree biomass

Step	Fixed area plots	Variable area plots
Step 1. Measurement (what is measured)	Individual tree dimension (e.g. diameter at breast height, diameter at root collar, tree height)	Basal area per hectare
Step 2. Conversion (how measurements are converted into tree biomass)	1. Using allometric equations based on tree dimensions; or 2. Using biomass expansion factors; or 3. Combination of 1 and 2	1. Using allometric equations based on basal area; or 2. Using biomass expansion factors; or 3. Combination of 1 and 2

Note. Sampling by variable area plot method is also termed as ‘angle count sampling’ in forest inventory literature.

1. Measurement of fixed area plots

2. In this method, sample plots of the same size (e.g. $\frac{1}{10}$ or $\frac{1}{20}$ of a hectare) are installed in a stratum. All trees in a sample plot above a minimum dimension are measured and the biomass of each tree is estimated. The minimum dimension selected can be low (e.g. a diameter of 2 cm) or high (e.g. a diameter of 10 cm) depending upon the applicability of models (e.g. allometric equations or volume equations) to be used for conversion of the tree dimension into tree volume or tree biomass, and upon cost-effectiveness of measurement.

3. The biomass of the individual trees is added and the sum is divided by the area of the sample plot to obtain the plot biomass value.

Note. Where the number of saplings with diameter below the range of diameter applicable to the allometric equation is high, the mean biomass of the saplings in a sample plot can be estimated as follows: (1) Determine the diameter mid-way between the diameter of the smallest sapling existing and the smallest diameter allowed by the allometric equation. (2) Harvest from outside the plot area a few saplings having diameter close to the mid-way diameter and obtain the mean biomass per sapling; (3) Count all the saplings in the sample plot and multiply this number by the mean sapling biomass to obtain their contribution to the plot biomass.

4. The plot biomass value (i.e. per-hectare tree biomass at the centre of the plot) is estimated as follows (all time-dependent variables relate to the time of measurement):

$$b_{TREE,p,i} = \frac{B_{TREE,p,i}}{A_{PLOT,i}}$$ Equation (1)

$$B_{TREE,p,i} = \sum_{j} B_{TREE,j,p,i}$$ Equation (2)

$$B_{TREE,j,p,i} = \sum_{l} B_{TREE,l,j,p,i}$$ Equation (3)

Where:

$b_{TREE,p,i}$	=	ee biomass per hectare in sample plot *p* of stratum *i*; t d.m. ha^{-1}
$B_{TREE,p,i}$	=	Tree biomass in sample plot *p* of stratum *i*; t d.m.
$A_{PLOT,i}$	=	Size of sample plot in stratum *i;* ha
$B_{TREE,j,p,i}$	=	Biomass of trees of species *j* in sample plot *p* of stratum *i*; t d.m.
$B_{TREE,l,j,p,i}$	=	Biomass of tree *l* of species *j* in sample plot *p* of stratum *i*; t d.m.

5. Biomass of a tree in a sample plot is estimated by using one of the following equations:

$$B_{TREE,l,j,p,i} = f_j(x_{1,l}, x_{2,l}, x_{3,l}, \dots) \times (1 + R_j)$$ Equation (4)

$$B_{TREE,l,j,p,i} = V_{TREE,j}(x_{1,l}, x_{2,l}, x_{3,l}, \dots) \times D_j \times BEF_{2,j} \times (1 + R_j)$$ Equation (5)

Where:

$B_{TREE,l,j,p,i}$	=	Biomass of tree *l* of species *j* in sample plot *p* of stratum *i*; t d.m.
$f_j(x_{1,l}, x_{2,l}, x_{3,l}, \dots)$	=	Above-ground biomass of the tree returned by the allometric equation for species *j* relating the measurements of tree *l* to the above-ground biomass of the tree*;* t d.m. Note. The allometric equation used may be based on different units of inputs and outputs. For example, input values of diameter at breast height (dbh) may be in inches and output of biomass may be in pounds, rather than dbh in cm and biomass in kg or t d.m. In such a case, the function should be applied consistently (e.g. convert the dbh values from centimetre to inch units, obtain the tree biomass in pound, and then convert the biomass into metric tonne).

R_j	=	Root-shoot ratio for tree species *j*; dimensionless The value of R_j is estimated as $R_j = \frac{e^{(-1.085+0.9256 \times \ln b)}}{b}$ where b is the above-ground tree biomass per hectare (in t d.m. ha^{-1}), unless transparent and verifiable information can be provided to justify a different value. Note. If trees have grown as coppice regeneration after a harvest, then the value of R_j should be multiplied by a factor equal to $^{v_{HARVEST}}/_{v_{TREE}}$ or 1, whichever is greater, where $v_{HARVEST}$ is the volume per hectare of trees harvested and v_{TREE} is the volume per hectare of trees standing in the plot at the time of measurement.
$V_{TREE,j}(x_{1,l}, x_{2,l}, x_{3,l}, \ldots)$	=	Stem volume of tree *l* of species *j* in sample plot *p* of stratum *i*, estimated from the tree dimension(s) as entry data into a volume table or volume equation; m^3 Note. Where the volume table or volume equation predicts under-bark volume (i.e. wood volume, rather than gross stem volume), suitable correction should be applied to estimate the over-bark volume.
D_j	=	Density (over-bark) of tree species *j*; t d.m. m^{-3} Values are taken from Table 3A.1.9 of IPCC GPG-LULUCF 2003 unless transparent and verifiable information can be provided to justify different values. Note. Where density (specific gravity) of the bark of a tree species is different from the density of the wood, suitable correction should be applied to estimate a conservative value of the overall (over-bark) density of tree stem.
$BEF_{2,j}$	=	Biomass expansion factor for conversion of tree stem biomass to above-ground tree biomass, for tree species *j*; dimensionless For ex-ante estimation, the value of $BEF_{2,j}$ is selected by applying, *mutatis mutandis*, the procedure described in paragraph 7 below. For ex-post estimation the conservative default value of 1.15 is used, unless transparent and verifiable information can be provided to justify a different value.

10. For ex-ante estimation the allometric equation, or volume table or volume equation applied to a tree species is selected from the following sources (the most preferred source being listed first):

    (a) Existing data applicable to local situation (e.g. represented by similar ecological conditions);

(b) National data (e.g. from national forest inventory or national greenhouse gas (GHG) inventory);

(c) Data from neighbouring countries with similar conditions;

(d) Globally applicable data.

11. For ex-post estimation, the allometric equation used must be demonstrated to be appropriate for the purpose of estimation of tree biomass by applying the tool "Demonstrating appropriateness of allometric equations for estimation of aboveground tree biomass in A/R CDM project activities", and the volume table or volume equation used must be demonstrated to be appropriate for the purpose of estimation of tree biomass by applying the tool "Demonstrating appropriateness of volume equations for estimation of aboveground tree biomass in A/R CDM project activities".

2. Measurement of variable plots

12. This method estimates tree biomass per hectare from the basal area per hectare and therefore does not require individual tree measurements. Tree basal area is obtained at the centre of a sample plot using an angle-count instrument (e.g. a wedge prism or a relascope).

13. Tree biomass in a plot is estimated as follows:

$$b_{TREE,p,i} = \sum_{j} b_{TREE,j,p,i} \qquad \text{Equation (6)}$$

Where:

$b_{TREE,p,i}$	=	Tree biomass per hectare in sample plot *p* of stratum *i*; t d.m. ha^{-1}
$b_{TREE,j,p,i}$	=	Tree biomass per hectare of species *j* in sample plot *p* of stratum *i*; t d.m. ha^{-1}

14. Tree biomass per hectare of a species in a sample plot is estimated by using one of the following equations:

$$b_{TREE,j,p,i} = f_j(BA_{p,i}) \times (1 + R_j) \qquad \text{Equation (7)}$$

$$b_{TREE,j,p,i} = v_{TREE,j}(BA_{p,i}) \times D_j \times BEF_{2,j} \times (1 + R_j) \qquad \text{Equation (8)}$$

Where:

$b_{TREE,j,p,i}$	=	Tree biomass per hectare of species *j* in sample plot *p* of stratum *i*; t d.m. ha^{-1}
$f_j(BA_{p,i})$	=	Above-ground tree biomass per hectare in plot *p* returned by the allometric equation for species *j* relating the basal area of the plot to the above-ground tree biomass per hectare; t d.m. ha^{-1}

$v_{TREE,j}(BA_{p,i})$ = Stem volume per hectare of trees of species *j* in sample plot *p* of stratum *i* estimated by using the basal area of the plot as entry data into a volume table or volume equation; $m^3\ ha^{-1}$

15. All other symbols have the same meanings and requirements as in Equations (4) and (5).

16. Requirements under paragraphs 7 and 8 above also apply, *mutatis mutandis*, in respect of allometric equations and volume functions used under this method.

Appendix 2. Applying uncertainty discount

1. Estimates with high uncertainty can be used in methodologies only if such estimates are conservative. This appendix provides a procedure for applying discount factors in order to make the mean estimated values of parameters conservative.

2. When the uncertainty in the estimated mean value of a parameter is more than 10 per cent, the estimated mean value is either increased or decreased by a percentage of the uncertainty. Table 1 provides the uncertainty discount factors to be applied for different ranges of uncertainty.

Table 1. Uncertainty discount factors

<table>
<tr><th>Uncertainty</th><th>Discount (% of U)</th><th>How applied</th></tr>
<tr><td>U ≤ 10%</td><td>0%</td><td rowspan="5">Example:
Estimated mean = 60±9 t d.m ha^{-1}
i.e. U=9/60x100 = 15%
Discount = 25% x 9 = 2.25 t d.m ha^{-1}
Discounted conservative mean:
In baseline = 60+2.25 = 62.25 t d.m ha^{-1}
In project = 60-2.25 = 57.75 t d.m ha^{-1}</td></tr>
<tr><td>10 < U ≤ 15</td><td>25%</td></tr>
<tr><td>15 < U ≤ 20</td><td>50%</td></tr>
<tr><td>20 < U ≤ 30</td><td>75%</td></tr>
<tr><td>U > 30</td><td>100%</td></tr>
</table>

Appendix 3. Calculating correlation coefficient and slope of regression

1. This appendix provides the formulae for calculation of the coefficient of correlation and the slope of regression line between two data sets. The formulae provided here can also be found in any textbook or reference book of statistics. It is only for convenience of the users and for avoiding any ambiguity in definition of these parameters that these formulae are provided here. These coefficients may also be calculated using commercial or open source computer software (e.g. statistical packages).

2. For two linearly related data sets of equal size, the correlation coefficient and the slope of regression line are calculated as follows:

$$\beta = \rho \times \frac{s_y}{s_x}$$ Equation (1)

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

Where:

β	=	Slope of regression line of the dependent variable (y) against the independent variable (x)
ρ	=	Sample correlation coefficient between the dependent variable (y) and the independent variable (x)
s_y, s_x	=	Sample standard deviation of the dependent variable (y) values and the independent variable (x) values respectively
x_i	=	Independent variable (x) values
$\bar{x}$	=	Mean of the independent variable (x) values
y_i	=	Dependent variable (y) values
$\bar{y}$	=	Mean of the dependent variable (y) values
n	=	Number of data values in each data set

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Document information

Version	*Date*	*Description*
Draft 05.0	4 October 2013	To be considered by the Board at EB 75. This version now includes a cover note.
04.0	21 August 2013	A/R WG 38, Annex 1 This draft version includes input from the call for public inputs from 24 May 2013 to 24 June 2013. In this revision: • Options of using double sampling and simplified method of ‘no-decrease’ were added; • Combining different methods in different strata was allowed; • A more comprehensive approach to uncertainty management was provided; • The structure was improved and some sections were moved to the appendices to improve readability; • Due to the overall modification of the document, no highlights of the changes are provided.
03.0.0	23 November 2012	EB 70, Annex 35 In this revision: (i) step-wise guidance was provided which explains when to use which method of estimation; (ii) effect of the tree bark density was taken into account to estimate tree biomass; (iii) a method for adjustment of the estimated mean values was provided when the uncertainty of estimation exceeds the allowable maximum uncertainty. Due to the overall modification of the document, no highlights of the changes are provided.

Version	*Date*	*Description*
02.1.0	15 April 2011	EB 60, Annex 13 In this amendment: (i) equations for estimation of the means and variances of tree biomass at stratum level and at project level have been included; (ii) estimation of tree biomass is made on a per hectare basis, so that plotless sampling (point sampling) methods can be seamlessly applied; (iii) an approach for estimation of change in biomass based on successive measurements of the same plots has been added; (iv) some entries in data and parameter tables have been updated to include more clear guidance in commonly encountered field situations; (iv) bark correction has been proposed in cases where a volume table based on under-bark volume is used in conjunction with biomass expansion factors based on over-bark volume (or vice versa).
02.0.0	17 September 2010	EB 56, Annex 13 In this revision: (i) the scope of the tool has been expanded so that it can be applied in both baseline scenario and project scenario; (ii) the procedure for estimation of shrub biomass has been simplified by adopting a default estimation approach based on a fraction of forest biomass; (iii) the mathematical notation and equations have been changed so to streamline these; (iv) general layout and style of the document has been changed so as to make it in conformity with other documents such as the recently approved A/R methodologies; and (v) the title was changed to “Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities” from the previous title “Estimation of changes in the carbon stocks of existing trees and shrubs within the boundary of an A/R CDM project activity”. Due to the overall modification of the document, no highlights of the changes are provided.
01	25 March 2009	EB 46, Annex 18 Initial adoption.

Decision Class: Regulatory
Document Type: Tool
Business Function: Methodology
Keywords: afforestation reforestation, AR project activity, biomass, carbon pools