CLEAN DEVELOPMENT MECHANISM

AR-TOOL14

Methodological tool

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

Version 04.0.0

United Nations
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1. Introduction

1. This tool provides step-by-step methods for estimation of carbon stock in biomass of trees and shrubs. For ex ante (projected) estimation of tree biomass it applies tree/stand growth models and for ex post (actual) estimation of tree biomass it uses field measurement data from sample plots. Biomass of shrubs is estimated from field measurement of the 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 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 C stock and change in C stock in trees and shrubs in baseline;

(b) Ex ante estimation (projection) of C stock and change in C stock in trees and shrubs in project;

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

2.2. Applicability

3. This tool has no internal applicability conditions.

2.3. Entry into force

4. The date of entry into force of the revision is the date of the publication of the EB xx meeting report on <date>.

3. Definitions and notation

5. This tool uses the following definitions:

(d) “Uncertainty” in the mean value of an estimated parameter is equal to the standard error of the mean expanded at 90% 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±3.72 t d.m. ha^{-1}, where the confidence interval (i.e. ±3.72) was estimated at 90% confidence level. This implies that the estimated mean has an uncertainty of (3.72/45) ×100 = 8.27%.

(e) “Species” also includes a group of species when the biometric parameter relating to the species (e.g. biomass expansion factor, root-shoot ratio, basic wood density, carbon fraction) or a model (e.g. allometric equation, volume table) is applicable to more than one species.

(f)

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

(g) 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});

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

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

(a) Biomass is expressed in tonne dry matter abbreviated as *t d.m.*, or in tonne dry matter per hectare abbreviated as $t\ d.m.\ ha^{-1}$;

(b) Carbon stocks and changes in carbon stocks are expressed in tonne carbon dioxide equivalent, abbreviated as *tCO2-e*.

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_2 e	Carbon stock in tree biomass within the project boundary at a given point of time in year *t*
$\Delta C_{TREE,t}$	t CO_2 e	Change in carbon stock in tree biomass within the project boundary in year *t*
$C_{SHRUB,t}$	t CO_2 e	Carbon stock in shrub biomass within the project boundary at a given point of time in year *t*
$\Delta C_{SHRUB,t}$	t CO_2 e	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. Estimating change in carbon stocks in trees between two points of time

10. Change in carbon stock in trees between two points of time is estimated by using one of the following methods:

   (a) Difference of two independent estimations (inventories);

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

   (c) Estimation by proportionate crown cover;

   (d) Demonstration of “no-decrease”.

5.1. Difference of two independent estimations (inventories)

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

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

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

Where:

ΔC_{TREE}	=	Change in carbon stock in tree biomass during the period between two points of time t_1 and t_2; t CO_2-e
C_{TREE,t_2}	=	Carbon stock in tree biomass at time t_2; t CO_2-e
C_{TREE,t_1}	=	Carbon stock in tree biomass at time t_1; t CO_2-e *Note.* At the first verification this is set equal to the pre-project tree biomass (C_{TREE_BSL}). However, this may be set equal to zero, if all of the following conditions are met: (i) The pre-project trees are neither harvested, nor cleared, nor removed throughout the crediting period of the project activity; (ii) 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; (iii) The pre-project trees are not inventoried along with the project trees in monitoring of tree carbon stocks but their continued existence, consistent with the baseline scenario, is monitored throughout the crediting period of the project activity.
$u_{\Delta C}$	=	Uncertainty in ΔC_{TREE}
u_1, u_2	=	Uncertainties in C_{TREE,t_1} and C_{TREE,t_2} respectively

12. Carbon stock in tree biomass at a point of time is estimated by using one of the applicable methods provided in Section 7.

13. If $u_{\Delta C}$ estimated from Equation (2) is greater than 10%, then ΔC_{TREE} is made conservative by applying the procedure provided in appendix 1.

5.2. Direct estimation by re-measurement of sample plots

14. This method is applicable only in *ex post* estimation of change in C stock in trees for monitoring of project activities. Under this method, the change in tree biomass in the sample plots is measured by measuring the same plots on two successive occasions.

15. The change in carbon stock and the associated uncertainty are estimated as follows:

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

$$\Delta B_{TREE} = A \times \Delta b_{TREE}$$ 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 tree biomass between two successive measurements; t CO_2-e
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 project boundary; t d.m.
A	=	Sum of areas of the biomass estimation strata; ha
Δb_{TREE}	=	Mean change in carbon stock per hectare in tree biomass within the project boundary; t d.m. ha^{-1}
		Note. This is equal to the difference between tree biomass per hectare at the two successive plot measurements.
w_i	=	Ratio of the area of stratum *i* (A_i)to the sum of areas of biomass estimation strata (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: (i) Degrees of freedom equal to *n* – *M*, where *n* is total number of sample plots within the project boundary, and *M* is the total number of tree biomass estimation strata; and (ii) a confidence level of 90%.
$s^2_{\Delta,i}$	=	Variance of change in tree biomass per hectare across all plots 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

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

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

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

Where:

$\Delta b_{TREE,i}$	=	Mean change in carbon stock per hectare in tree biomass in stratum *i*; t d.m. ha^{-1}
$\Delta b_{TREE,p,i}$	=	Change in tree biomass per hectare in plot p; t d.m. ha^{-1}
$s^2_{\Delta,i}$	=	Variance of change in tree biomass per hectare across sample plots 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

17. If $u_{\Delta C}$ estimated from Equation (6) is greater than 10%, then ΔC_{TREE} is made conservative by applying the procedure provided in appendix 2.

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

5.3. Estimation by proportionate crown cover

19. This method is applicable only in ex ante estimation of change in C stock in trees in the baseline where the mean pre-project tree crown cover is less than 20% of the threshold 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 crown cover of 30%. This method is applicable only if the mean pre-project tree crown cover is less than 20% of 30%, i.e. less than 6%).

20. 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}	=	Average annual change in carbon stock in tree biomass in the baseline; t CO_2-e yr^{-1}
$\Delta C_{TREE\_BSL,i}$	=	Average annual change in carbon stock in tree biomass in the baseline in baseline stratum *i*; t CO_2-e 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.
Δb_{FOREST}	=	Default average annual increment of above-ground biomass in forest in the region/country where the A/R CDM project is located; t d.m. ha^{-1} yr^{-1} Values from Table 3A.1.5 of IPCC GPG-LULUCF 2003 are used unless transparent and verifiable information can be provided to justify different values. *Note 1*. Tree biomass may reach a steady state when 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 baseline reaches a steady state. The year in which tree biomass in baseline reaches steady-state is taken to be the 20^{th} year from the start of the CDM project activity, unless transparent and verifiable information can be provided to justify a different year. *Note 2.* When land is subjected to periodic slash-and-burn cycles in the baseline, the value of this parameter is set equal to zero.
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% crown cover implies $CC_{TREE\_BSL,i}$ = 0.10); dimensionless
A_i	=	Area of stratum *i* in the baseline, delineated on the basis of tree crown cover at the start of the A/R CDM project activity; ha

5.4. Demonstration of “no-decrease”

21. Project participants may, at the time of a verification, prove that tree biomass in one or more strata has not decreased relative to the tree biomass at the time of the previous verification, by demonstrating that:

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

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

(c) Remote sensing data or a participatory rural appraisal data demonstrate that tree crown cover in the stratum has not decreased since the previous verification.

22. Where all the three conditions above are demonstrated to have been met, the change in carbon stock in trees since the previous verification may be conservatively accounted as zero.

6. Estimating change in carbon stocks in trees in a year

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

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

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

Where:

$\Delta C_{TREE,t}$	=	Change in carbon stock in tree biomass during a year *t* between two points of time t_1 and t_2; t CO_2-e
C_{TREE,t_2}	=	Carbon stock in tree biomass at time t_2; t CO_2-e
C_{TREE,t_1}	=	Carbon stock in tree biomass at time t_1; t CO_2-e
T	=	Time elapsed between two successive estimations ($T=t_2 - t_1$); yr *Note.* Value of *T* can be a fractional value.

7. Estimating carbon stocks in trees at a point of time

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

(a) Measurement of sample plots

(b) Modelling of tree and stand growth

(c) Proportionate crown cover

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

26. These methods apply differently for ex ante and ex post estimation of carbon stock in trees in baseline and project scenarios as provided in Table 2.

Table 2: Methods available for estimation of carbon stock in trees

Estimation type	**Estimation in baseline**	**Estimation in project**
Ex ante	• Measurement of sample plots • Modelling of tree and stand growth • Proportionate crown cover	• Modelling of tree and stand growth
Ex post	NA	• Measurement of sample plots

27. When estimation is carried out by methods (a), (c) or (d) above, the date of last measurement or estimation of crown cover is considered to be the date to which the estimation relates, even though the full process of measurement was extended over a longer period of time.

7.1. Estimating by measurements of sample plots

28. Under this method, carbon stock in tree biomass is estimated on the basis of measurements of sample plots. Sample plots may be installed in one or more strata whose individual areas sum up to the total project area. Two sampling methods are available under this method:

(a) Stratified random sampling

(b) Double sampling

7.1.1. Stratified random sampling

29. Under this method, the project area is stratified into one or more strata. Sample plots are installed in the strata, preferably with different sampling intensities. Tree biomass is measured in all the sample plots in each stratum.

30. Mean carbon stock in tree biomass within the project boundary 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 tree biomass within the project boundary; t CO_2-e
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 within the project boundary; t d.m.
A	=	Sum of areas of the biomass estimation strata within the project boundary; ha
b_{TREE}	=	Mean carbon stock per hectare in tree biomass within the project boundary; t d.m. ha^{-1}
w_i	=	Ratio of the area of stratum *i* (A_i)to the sum of areas of biomass estimation strata (A); dimensionless
$b_{TREE,i}$	=	Mean carbon stock per hectare in tree biomass in stratum *i*; t d.m. ha^{-1}
u_C	=	Uncertainty in C_{TREE}
t_{VAL}	=	Two-sided Student's *t*-value for: (i) Degrees of freedom equal to *n* – *M*, where *n* is total number of sample plots within the project boundary, and *M* is the total number of tree biomass estimation strata; and (ii) a confidence level of 90%.
s_i^2	=	Variance of tree biomass per hectare across all plots in stratum *i*; (t d.m. ha^{-1})^2
n_i	=	Number of sample plots in stratum *i*.

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

$$b_{TREE,i} = \frac{\sum_p b_{TREE,p,i}}{n_i}$$ 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 tree biomass per hectare across all the plots in stratum *i*; (t d.m. ha^{-1})^2

n_i	=	Number of sample plots in stratum *i*.

32. If u_C estimated from Equation (15) is greater than 10%, then C_{TREE} is made conservative by applying the procedure provided in appendix 2.

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

7.1.2. Double sampling

34. 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 sample plots. This method is applicable only if the regression of the plot biomass values against the secondary variable is linear (i.e. the best-fit curve is a straight line).

35. Equations (12) – (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):

$$b_{TREE,i} = \frac{\sum_p b_{TREE,p,i}}{n_i} + \beta \times (\overline{x'} - \bar{x})$$ 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 stratum *i*
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 the full sample of 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 tree biomass per hectare across all the sample plots 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
ρ	=	Coefficient of correlation between the secondary variable and the tree biomass per hectare in a sample plot, estimated across the sample plots in the sub-sample

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

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

38. If u_C estimated from Equation (15) is greater than 10%, then C_{TREE} is made conservative by applying the procedure provided in appendix 2.

7.2. Estimating by modelling of tree growth and stand development

39. 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 tree stand over time.

40. Stand parameters such as stocking (stand density), 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/ pruning operations and their timing).

41. 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, precipitation) and stand parameters.

42. Ex ante estimation (projection) of carbon stock in tree biomass is not subjected to uncertainty control, although it is a best practice to use the data and models that apply most accurately to the project site and the tree species.

7.3. Estimating by proportionate crown cover

43. This method is applicable only for estimation of the initial (pre-project) carbon stock in tree biomass in the baseline where the mean pre-project tree crown cover is less than 20% of the threshold 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 crown cover of 30%. This method is applicable only if the mean pre-project tree crown cover is less than 20% of 30%, i.e. less than 6%).

44. Carbon stock in tree biomass is estimated by proportionate 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 on the basis of pre-project tree crown cover.

45. 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 initial (pre-project) tree biomass in the baseline; t CO_2-e

$C_{TREE\_BSL,i}$	=	Carbon stock in initial (pre-project) tree biomass in the baseline in stratum *i*; t CO_2-e
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}	=	Default average above-ground biomass in forest in the region/ 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 the baseline, in baseline stratum *i*, at the start of the A/R CDM project activity, expressed as a fraction (e.g. 10% crown cover implies $CC_{TREE\_BSL,i}$ = 0.10); dimensionless
A_i	=	Area of stratum *i* in the baseline, delineated on the basis of tree crown cover at the start of the A/R CDM project activity; ha

7.4. Updating previous stock by direct estimation of change

46. 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 at the previous verification.

47. The carbon stock in tree biomass in a stratum and the associated uncertainty are estimated as follows:

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

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

Where:

ΔC	=	Change in carbon stock in tree biomass during the period between a times t_1 and t_2; t CO_2-e
C_1	=	Carbon stock in tree biomass at time t_2; t CO_2-e
C_2	=	Carbon stock in tree biomass at time t_1; t CO_2-e
$u_{\Delta C}$	=	Uncertainty in ΔC_{TREE}
u_2, u_1	=	Uncertainties in C_{TREE,t_2} and C_{TREE,t_1} respectively

48. If u_2 estimated from Equation (23) is greater than 10%, then C_{TREE,t_2} is made conservative by applying the procedure provided in appendix 2.

8. Estimating change in carbon stocks in shrubs between two points of time

49. 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

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

9. Estimating change in carbon stocks in shrubs in a year

51. Change in carbon stock in shrubs in a year (annual change) between two successive verifications is estimated on the approximation assumption of linear (uniform) change. Change in carbon stock in shrubs in a year is estimated as:

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

Where:

$\Delta C_{SHRUB,t}$	=	Change in carbon stock in shrub biomass in year *t* between times t_1 and t_2; t CO_2-e
C_{SHRUB,t_2}	=	Carbon stock in shrub biomass at time in t_2; t CO_2-e
C_{SHRUB,t_1}	=	Carbon stock in shrub biomass at time t_1; t CO_2-e
T	=	Time elapsed between two successive estimations ($T = t_2 – t_1$); yr *Note.* The value of T can be a fraction.

10. Estimating carbon stocks in shrubs at a point of time

52. Carbon stock in shrub biomass is estimated by proportionate crown cover method. The area within the project boundary is stratified on the basis of shrub crown cover.

53. Carbon stock in shrub biomass is estimated as follows:

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

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

Where:

C_{SHRUB}	=	Carbon stock in shrub biomass at a point of time; t CO_2-e
CF_s	=	Carbon fraction of shrub biomass; t C (t.d.m.)$^{-1}$ IPCC default value of 0.47 t C (t.d.m.)$^{-1}$ is used
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 stratum *i*; ha
$b_{SHRUB,i}$	=	Shrub biomass per hectare in shrub biomass 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%) and the default above-ground biomass content per hectare in forest in the region/country where the A/R CDM project 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 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 stratum *i* at the time of estimation, expressed as a fraction (e.g. 10% crown cover implies $CC_{SHRUB,i}$ = 0.10); dimensionless

54. For those strata where the shrub crown cover is less than 5 per cent, the shrub biomass per hectare is considered negligible and hence accounted as zero

11. Data and parameters used in the tool

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

11.1. Data / parameters not monitored

56. 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.

11.2. Data / parameters monitored.

57. The requirements for data and parameters subject to monitoring are provided in data description tables in this below.

Table 1. Area of land

Data / Parameter:	$A_{PLOT,i}$, $A_{SHRUB,i}$, 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

Table 2. Shrub crown cover

Data / Parameter:	$\boldsymbol{CC_{SHRUB,i}}$
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 slash-and-burn cycles in the baseline, an average shrub crown cover equal to default value of 0.5 is used unless transparent and verifiable information can be provided to justify a different value.

Table 3. Tree crown cover

Data / Parameter:	$CC_{TREE\_BSL,i}$
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:	Where slash-and-burn practices are present in the baseline and the trees are slashed or burnt, or slashed and burnt, the value of this parameter should be set equal to half the maximum tree crown cover that would be achieved under the slash-and-burn practices.

Appendix 1. Estimating tree biomass in a sample plot

1. This appendix provides methods for estimation 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	1. Using allometric equations based on basal area; or 2. Using biomass expansion factors

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, all the sample plots are of the same size (e.g. $\frac{1}{10}$ or $\frac{1}{20}$ of a hectare). All trees in a sample plot above a minimum diameter are measured and the biomass of each tree is estimated. 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.

3. The plot biomass value 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)

Where:

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

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

$$B_{TREE,j,p,i} = f_j(x_1, x_2, x_3, \dots) \times (1 + R_j)$$ Equation (3)

$$B_{TREE,j,p,i} = V_{TREE,j,p,i} \times D_j \times BEF_{2,j} \times (1 + R_j)$$ Equation (4)

Where:

$B_{TREE,j,p,i}$	=	Biomass of a tree of species *j* in sample plot *p* of stratum *i*; t d.m.
$f_j(x_1, x_2, x_3, \dots)$	=	Function relating tree measurements $(x_1, x_2, x_3, \dots)$ to the above-ground biomass of a tree of species *j*.
R_j	=	Root-shoot ratio for tree species *j*; dimensionless The value of R_j is calculated as $R_j = \frac{e^{(-1.085+0.9256 \times \ln A)}}{A}$ where A 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.
$V_{TREE,j,p,i}$	=	Stem volume of a tree 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/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 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 biomass.

$BEF_{2,j}$	=	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 taken from Table 3A.1.10 of IPCC GPG-LULUCF 2003 unless transparent and verifiable information can be provided to justify a different value. 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.

7. For ex ante estimation the allometric equation or volume table/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.

8. 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 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

9. 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 equipment (e.g. a wedge prism or a relascope).

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

Equation (5)

$$b_{TREE,p,i} = \sum_{j} b_{TREE,j,p,i}$$

Where:

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

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

$$b_{TREE,j,p,i} = f_j(BA) \times (1 + R_j)$$ Equation (6)

$$b_{TREE,j,p,i} = v_{TREE,j,p,i} \times D_j \times BEF_{2,j} \times (1 + R_j)$$ Equation (7)

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}
$f_j(BA)$	=	Function relating tree basal area to the tree biomass per hectare of tree species *j*.
$v_{TREE,j,p,i,t}$	=	Stem volume per hectare of trees of species *j* in sample plot *p* of stratum *i* estimated by using the basal area as entry data into a volume table or volume equation; m^3 h^{-1}

All other symbols have the same meaning and requirements as in Equations (3) and (4).

12. 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%, the estimated mean value is either increased or decreased by a percentage of the uncertainty (i.e. half the width of the confidence interval). Table 1 provides the uncertainty discount factors to be applied for different ranges of uncertainty. These factors only apply to symmetrical uncertainty intervals.

Table 1. Uncertainty discount factors

Uncertainty	Discount (% of U)	How applied
U ≤ 10%	0%	*Example:* Estimated mean = 60±9 t d.m ha^{-1} i.e. U=9/60x100 = 15% Adjustment = 25% x 9 = 2.25 t d.m ha^{-1} Adjusted 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}
10 < U ≤ 15	25%	
15 < U ≤ 20	50%	
20 < U ≤ 30	75%	
U > 30	100%	

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 mathematics or 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 or statistical packages.

2. For two 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*
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.
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.

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