CLEAN DEVELOPMENT MECHANISM

CDM-ARWG37-A03

Draft Methodological tool

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

Version 03.0.0

United Nations
Framework Convention on
Climate Change

COVER NOTE

1. Procedural background

1. This draft revision of the tool forms part of the work of improvement of the A/R methodological standards undertaken by the A/R Working Group (the A/R WG) as mandated in the work plan of the group approved in the CDM MAP 2012.

2. Purpose

2. This draft revision of the tool is intended to improve environmental integrity of the tool as well as to facilitate usability and accessibility of the tool.

3. Key issues and proposed solutions

3. This draft revision of the tool addresses the following key issues:

   (a) Step-wise guidance has been provided which explains when to use which method of estimation;

   (b) Effect of the tree bark density has been taken into account to ensure that no overestimation of tree biomass occurs;

   (c) A method for adjustment of the estimated mean values has been provided when the uncertainty of estimation exceeds the allowable maximum uncertainty.

4. Impacts

4. This draft revision of the tool will improve environmental integrity, usability and accessibility of the tool. It will, however, not affect adversely the projects that are already registered.

5. Proposed work and timelines

5. This draft revision of the tool has been agreed by the A/R WG to be recommended for approval by the Board. Approval of the draft revised tool will complete the present task.

6. Recommendations to the Board

6. The A/R WG recommends that the Board approve the draft revised tool.

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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 estimation of tree biomass it applies tree/stand growth models and for ex post 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. The tool does not include use remote sensing methods or regression-based sampling methods.

2. Scope, applicability, and entry into force

2.1. Scope

2. This tool can be used for estimation of carbon stocks and change in carbon stocks of trees and shrubs in the baseline and project scenarios of an A/R CDM project activity.

2.2. Applicability

3. This tool has no internal applicability conditions, but makes the following assumptions:

(a) Growth of biomass in trees and shrubs may be assumed to proceed on average at an approximately constant rate between two consecutive monitoring points in time at which biomass is estimated;

(b) Root-shoot ratios appropriate for estimation of below-ground biomass from above-ground biomass under forest/continuous-cover conditions are appropriate for all trees and shrubs within the project boundary.

2.3. Entry into force

4. The date of entry into force of the revision is the date of the publication of the EB 70 meeting report on 23 November 2012.

3. Definitions

5. This tool does not use internal definitions.

4. Parameters determined by the tool

6. This tool provides procedures to determine the following parameters:

Table 1. Parameters determined by the tool

Parameter	SI 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*

7. While applying this tool in a methodology, the following notation 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 $\Delta C_{SHRUB,t}$

8. For the purpose of this tool, the term "species" also implies a group of species when a biometric parameter (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.

5. Procedures for estimating ex ante change in carbon stocks in the baseline

9. Change in carbon stock in trees in the baseline is estimated using the following step-wise procedure.

(a) Select the technique and use the appropriate equation for estimating the carbon stock in trees;

Table 2. Techniques for estimating ex ante change in carbon stocks in the baseline

Technique	Equation number
Biomass expansion factor (BEF) technique	1
Allometric equation technique	2
Baseline default technique	3,4

(b) Select the method and use the appropriate equation for estimating the carbon stock change in trees.

Table 3. Methods for estimating ex ante change in carbon stocks in the baseline

Method	Equations number
Stock change method	5 – 15 Omit equations 8, 9, 11
Increment method	Not applicable
Baseline default method	28, 29

6. Procedures for estimating ex ante change in carbon stocks within the project boundary

10. Change in carbon stock in trees in the project is estimated ex ante using the following step-wise procedure.

(a) Select the technique and use the appropriate equation for estimating the carbon stock in trees (section V);

Table 4. Techniques for estimating ex ante change in carbon stocks within the project boundary

Technique	Equation number
Biomass expansion factor (BEF) technique	1
Allometric equation technique	2
Baseline default technique	Not applicable

(b) Select the method use the appropriate equation for estimating the carbon stock change in trees (section VI).

Table 5. Methods for estimating ex ante change in carbon stocks within the project boundary

Method	Equations number
Stock change method	5 - 15 If the stem volume of trees is expressed in m^3 ha^{-1} then, apply equation 1 on a per hectare basis and go to equation 10. Otherwise, in equation 6 assume that the individual tree volumes are multiplied by the expected time-series stocking densities. Omit equations 8, 9, 11
Increment method	Not applicable
Baseline default method	Not applicable

7. Procedures for estimating ex post the change in carbon stocks within the project boundary

11. Change in carbon stock in trees in the project is estimated ex post using the following step-wise procedure.

(a) Select the technique and use the appropriate equations for estimating the carbon stock in trees (section V);

Table 6. Techniques for estimating ex post the change in carbon stocks within the project boundary

Technique	Equation number
Biomass expansion factor (BEF) technique	1
Allometric equation technique	2
Baseline default technique	Not applicable

(b) Select the method and use the appropriate equations for estimating the carbon stock change in trees (section VI). For the first verification event, the stock change method must be used.

Table 7. Methods estimating ex post the change in carbon stocks within the project boundary

Method	Equations number
Stock change method	5 – 15
Increment method	16 – 27
Baseline default method	Not applicable

8. Techniques for estimating C stock in trees

12. Carbon stock in tree biomass is estimated on the basis of one or more tree biomass strata.

13. The following techniques are available for estimating the C stock in trees:

(a) Biomass expansion factor (BEF) technique;

(b) Allometric equation technique;

(c) Baseline default technique.

8.1. Estimation of tree biomass using the BEF technique

14. In this technique, volume tables or volume equations are used to convert tree dimensions to stem volume of trees. Stem volume of trees is converted to above-ground tree biomass using density and biomass expansion factors, and the above-ground tree biomass is expanded to total tree biomass using root-shoot ratios. Thus, biomass of trees of species j in sample plot p is estimated as:

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

Where:

$B_{TREE,j,p,i,t}$	=	Biomass of trees of species *j* in sample plot *p* of stratum *i* at a point of time in year *t*; t dry matter (d.m.)
$V_{TREE,j,p,i,t}$	=	Stem volume of trees of species *j* in sample plot *p* of stratum *i* at a point of time in year *t*, estimated by using the tree dimension(s) as entry data into a volume table or volume equation; m^3
D_j	=	Density (overbark) of tree species *j*; t d.m. m^{-3}
$BEF_{2,j}$	=	Biomass expansion factor for conversion of stem biomass to above-ground tree biomass, for tree species *j*; dimensionless
R_j	=	Root-shoot ratio for tree species *j*; dimensionless
j	=	*1, 2, 3, …* tree species in plot *p*
p	=	*1, 2, 3, …* sample plots in stratum *i*

i	=	*1, 2, 3,* … tree biomass estimation strata within the project boundary
t	=	*1, 2, 3,* … years counted from the start of the A/R CDM project activity

15. For ex ante estimation $B_{TREE,j,p,i,t}$ may be estimated at species and stratum level using volume at species and stratum level, instead of plot level (for example; per hectare). The volume table or volume equation applicable 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 GHG inventory);

    (c) Data from neighbouring countries with similar conditions;

    (d) Globally applicable data.

16. For ex post estimation, 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".

8.2. Estimation of tree biomass using the allometric equation technique

17. Under this technique allometric equations are used to convert tree dimensions to above-ground biomass of trees and the above-ground tree biomass is expanded to total tree biomass using root-shoot ratios. Thus, biomass of trees of species *j* in sample plot *p* is calculated as:

$$B_{TREE,j,p,i,t} = f_{j(x1_{p,i,t}, x2_{p,i,t}, x3_{p,i,t,\dots})} \times \left(1 + R_j\right) \qquad \text{Equation (2)}$$

Where:

$B_{TREE,j,p,i,t}$	=	Biomass of trees of species *j* in sample plot *p* of stratum *i* at a given point of time in year *t*; t d.m.
$f_{j(x1_{p,i,t}, x2_{p,i,t}, x3_{p,i,t,\dots})}$	=	Function relating measured tree dimensions (x1, x2, x3, …) to above-ground biomass. Tree dimensions are measured in sample plot *p* of stratum *i* at a given point of time in year *t.* Tree dimensions x1, x2, x3, … could be, for example DBH, height of tree, etc.
R_j	=	Root-shoot ratio for tree species *j*; dimensionless
j	=	*1, 2, 3,* … tree species in plot *p*
p	=	*1, 2, 3,* … sample plots in stratum *i*

i	=	*1, 2, 3, …* tree biomass estimation strata within the project boundary
t	=	*1, 2, 3, …* years counted from the start of the A/R CDM project activity

18. For ex ante estimation the allometric equation applicable to a tree species is selected using the same procedure as prescribed for selection of volume tables or volume equations in paragraph 13 above.

19. 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".

8.3. Estimation of baseline tree biomass using the default technique

20. This method is applicable only for estimation of carbon stock in trees in the baseline when:

(a) Stock change cannot be applied for lack of data; or

(b) The mean tree crown cover in the baseline 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. (for example: if the threshold crown cover is 30%, then the mean tree crown cover is less than 6%).

21. Carbon stock in trees in the baseline is estimated as follows:

$$C_{TREE,BSL,i} = \frac{44}{12} \times CF_{TREE\_BSL} \times B_{FOREST} \times (1 + R_{TREE\_BSL}) \times CC_{TREE\_BSL,i} \times A_{BSL,i}$$ Equation (3)

$$C_{TREE\_BSL} = \sum_{i=1}^{M} C_{TREE\_BSL,i}$$ Equation (4)

Where:

C_{TREE_BSL}	=	Carbon stock in living trees in the baseline, in the project boundary, at the start of the A/R CDM project activity; t CO_2-e
$C_{TREE,BSL,i}$	=	Carbon stock in living trees in the baseline, in baseline stratum *i*, at the start of the A/R CDM project activity; t CO_2-e. Baseline strata are delineated on the basis of tree crown cover
CF_{TREE_BSL}	=	Carbon fraction of tree biomass in the baseline; t C $(t.d.m.)^{-1}$ A default value of 0.47 t C $(t.d.m.)^{-1}$ is used
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}

R_{TREE_BSL}	=	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
$A_{BSL,i}$	=	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
i	=	*1, 2, 3,* … tree biomass estimation strata within the project boundary

9. Methods for estimating change in C stock in trees

22. Change in carbon in trees is estimated by applying one of the following methods, each applicable under its specific conditions:

(a) Stock change method;

(b) Increment method;

(c) Baseline default method.

9.1. Stock change method

23. This method may be used to estimate the biomass of trees ex ante or ex post.

24. Under stock change method carbon stock in trees within the project boundary is estimated at successive points of time (e.g. in project, ex post estimation at successive verifications; in baseline, ex ante estimation at the start and the end of the crediting period). Change in carbon stock in trees between two successive points of time is calculated as the difference between the two estimated stocks.

25. For ex post estimation, this method is applicable when uses temporary or permanent sample plots and the marking of trees is not required. Under this method, first the carbon stock in trees at a point of time is estimated and then the change in carbon stock is calculated on the basis of two successive stock estimates.

26. The tree biomass in sample plot *p* of stratum *i* is estimated as follows:

$$B_{TREE,p,i,t} = \sum_{j} B_{TREE,j,p,i,t} \qquad \text{Equation (5)}$$

Where:

$B_{TREE,p,i,t}$	=	Tree biomass in sample plot *p* in stratum *i* at a given point of time in year *t*; t d.m.
$B_{TREE,j,p,i,t}$	=	Biomass of trees of species *j* in sample plot *p* of stratum *i* at a given point of time in year *t*; t d.m.

j	=	*1, 2, 3, …* species in plot *p*
p	=	*1, 2, 3*, … sample plots in stratum *i*
i	=	*1, 2, 3,* … strata used for tree biomass estimation within the project boundary
t	=	*1, 2, 3, …* years counted from the start of the A/R CDM project activity

27. Tree biomass per hectare in plot *p* in stratum *i* is estimated as follows:

$$b_{TREE,p,i,t} = \frac{B_{TREE,p,i,t}}{A_{p,i}} \qquad \text{Equation (6)}$$

Where:

$b_{TREE,p,i,t}$	=	Tree biomass per hectare in sample plot *p* in stratum *i* at a given point of time in year *t*; t d.m. ha^{-1}
$B_{TREE,p,i,t}$	=	Tree biomass in sample plot *p* in stratum *i* at a given point of time in year *t*; t d.m.
$A_{p,i}$	=	Area of sample plot *p* in stratum *i*; ha
p	=	*1, 2, 3*, … sample plots in stratum *i*
i	=	*1, 2, 3,* … tree biomass estimation strata within the project boundary
t	=	*1, 2, 3, …* years counted from the start of the A/R CDM project activity

28. Mean tree biomass per hectare in stratum *i* and the variance of tree biomass per hectare in the stratum are estimated as follows:

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

$$s_i^2 = \frac{n_i \ x \sum_{p=1}^{n_i} b_{TREE,p,i,t}^2 - \left(\sum_{p=1}^{n_i} b_{TREE,p,i,t} \right)^2}{n_i \times (n_i - 1)} \qquad \text{Equation (8)}$$

Where:

$b_{TREE,i,t}$	=	Mean tree biomass per hectare in stratum *i* at a given point of time in year *t*; t d.m. ha^{-1}
$b_{TREE,p,i,t}$	=	Tree biomass per hectare in sample plot *p* in stratum *i* at a given point of time in year *t*; t d.m. ha^{-1}

n_i	=	Number of sample plots in stratum *i*
s_i^2	=	Variance of tree biomass per hectare in stratum *i* at a given point of time in year *t*; (t d.m. ha^{-1})^2
p	=	*1, 2, 3*, … sample plots in stratum *i*
i	=	*1, 2, 3,* … tree biomass estimation strata within the project boundary
t	=	*1, 2, 3, …* years counted from the start of the A/R CDM project activity

29. Mean tree biomass per hectare within the project boundary and its variance are estimated as follows:

$$b_{TREE,t} = \sum_{i=1}^{M} w_i \times b_{TREE,i,t}$$ Equation (9)

$$s^2_{b_{TREE,t}} = \sum_{i=1}^{M} w_i^2 \times \frac{s_i^2}{n_i}$$ Equation (10)

Where:

$b_{TREE,t}$	=	Mean tree biomass per hectare within the project boundary at a given point of time in year *t*; t d.m. ha^{-1}
w_i	=	Ratio of the area of stratum *i* to the sum of areas of biomass estimation strata; dimensionless
$b_{TREE,i,t}$	=	Mean tree biomass per hectare in stratum *i* at a given point of time in year *t*; t d.m. ha^{-1}
$s^2_{b_{TREE,t}}$	=	Variance of mean tree biomass per hectare within the project boundary at a given point of time in year *t*; (t d.m. ha^{-1})^2
s_i^2	=	Variance of tree biomass per hectare in stratum *i* at a given point of time in year *t*; (t d.m. ha^{-1})^2
n_i	=	Number of sample plots in stratum *i*
M	=	Number of tree biomass estimation strata within the project boundary
p	=	*1, 2, 3*, … sample plots in stratum *i*
i	=	*1, 2, 3,* … tree biomass estimation strata within the project boundary
t	=	*1, 2, 3, …* years counted from the start of the A/R CDM project activity

30. Uncertainty of the mean tree biomass per hectare within the project boundary is estimated as:

$$u_{bTREE,t} = \frac{t_{VAL} \times s_{bTREE,t}}{b_{TREE,t}}$$ Equation (11)

Where:

$u_{bTREE,t}$	=	Uncertainty of tree biomass per hectare within the project boundary at a given point of time in year *t*; %
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%. For example two-sided Student's *t*-value for a probability value of 10% (which implies a 90% confidence level) and 45 degrees of freedom can be obtained in Excel spreadsheet as "=TINV(0.10,45)"[1] which returns a value of 1.6794
$s_{bTREE,t}$	=	Square root of the variance of mean tree biomass per hectare within project boundary at a given point of time in year *t* (i.e. the standard error of the mean); t d.m. ha^{-1}

31. Total tree biomass within the project boundary at a given point of time in year *t* is estimated as follows:

$$B_{TREE,t} = A \times b_{TREE,t}$$ Equation (12)

Where:

$B_{TREE,t}$	=	Total tree biomass within the project boundary at a given point of time in year *t*; t d.m.
A	=	Sum of areas of the biomass estimation strata within the project boundary; ha
$b_{TREE,t}$	=	Mean tree biomass per hectare within the project boundary at a given point of time in year *t*; t d.m. ha^{-1}
t	=	*1, 2, 3, …* years counted from the start of the A/R CDM project activity

32. Carbon stock in tree biomass within the project boundary at a given point of time in year *t* is estimated as follows:

$$C_{TREE,t} = \frac{44}{12} \times B_{TREE,t} \times CF_{TREE}$$ Equation (13)

[1] In Excel 2010, TINV has been replaced by T.INV.

Where:

$C_{TREE,t}$	=	Carbon stock in tree biomass within the project boundary at a given point of time in year *t*; t CO_2-e
$B_{TREE,t}$	=	Total tree biomass within the project boundary at a given point of time in year *t*; t d.m.
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
t	=	1, 2, 3, … years counted from the start of the A/R CDM project activity

33. Change in carbon stock in trees is calculated assuming that the rate of change of tree biomass over a period of time is calculated assuming a linear growth. Therefore, the rate of change in carbon stock in tree biomass over a period of time is calculated as follows:

$$dC_{TREE,(t_1,t_2)} = \frac{C_{TREE,t_2} - C_{TREE,t_1}}{T} \quad \text{Equation (14)}$$

Where:

$dC_{TREE,(t_1,t_2)}$	=	Rate of change in carbon stock in tree biomass within the project boundary during the period between a point of time in year t_1 and a point of time in year t_2; t CO_2-e yr^{-1}
C_{TREE,t_2}	=	Carbon stock in tree biomass within the project boundary at a point of time in year t_2; t CO_2-e
C_{TREE,t_1}	=	Carbon stock in tree biomass within the project boundary at a point of time in year t_1; t CO_2-e
T	=	Time elapsed between two successive estimations ($T=t_2 - t_1$); yr
t	=	1, 2, 3, … years counted from the start of the A/R CDM project activity

34. For the first verification, the variable C_{TREE,t_1} in Equation (14) is assigned the value of carbon stock in the tree biomass at the start of the A/R CDM project activity, that is: $C_{TREE,t_1} = C_{TREE\_BSL}$ for the first verification, where t_1 = 0 and t_2 = year of the first verification.

35. Change in carbon stock in tree biomass within the project boundary in year *t* ($t_1 \leq t \leq t_2$) is calculated as follows:

$$\Delta C_{TREE,t} = dC_{TREE,(t_1,t_2)} \times 1\ year \text{ for } t_1 \leq t \leq t_2 \quad \text{Equation (15)}$$

Where:

$\Delta C_{TREE,t}$	=	Change in carbon stock in tree biomass within the project boundary in year *t*; t CO_2-e
$dC_{TREE,(t_1,t_2)}$	=	Rate of change in carbon stock in tree biomass within the project boundary during the period between a point of time in year t_1 and a point of time in year t_2; t CO_2-e yr^{-1}
t	=	1, 2, 3, … years counted from the start of the A/R CDM project activity

9.2. Increment method

36. The increment method is used for ex post estimation of tree biomass in project when the same sample plots are measured over successive verifications. In the increment method, individual trees shall be given a unique identifier.[2] The change in biomass of individual trees is then monitored and estimated over time.

37. If a tree measured at the time of the earlier verification cannot be found at the time of the later verification (i.e. the tree is missing or is dead), then its biomass on the later verification is recorded as zero.[3]

38. If a new tree is found at the time of a later verification, then its biomass on the earlier verification is recorded as the biomass with the minimum biomass based on the sampling design. The new tree is found at the time of the later verification, this tree should be given a unique identifier.

39. Change in biomass of an individual tree *l* of species *j* in sample plot *p* of stratum *i* between two successive verifications is estimated as follows:

$$\Delta B_{TREE,l,j,p,i,(t_1,t_2)} = B_{TREE,l,j,p,i,t_2} - B_{TREE,l,j,p,i,t_1} \quad \text{Equation (16)}$$

Where:

$\Delta B_{TREE,l,j,p,i,(t_1,t_2)}$	=	Change in biomass of tree *l* of species *j* in sample plot *p* of stratum *i* between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m.
B_{TREE,l,j,p,i,t_2}	=	Biomass of tree *l* of species *j* in sample plot *p* of stratum *i* at time t_2; t d.m.
B_{TREE,l,j,p,i,t_1}	=	Biomass of tree *l* of species *j* in sample plot *p* of stratum *i* at time t_1; t d.m. For new trees identified at time2, biomass shall be set to the minimum biomass recorded
l	=	*1, 2, 3,* … trees of species *j* in plot *p*
j	=	*1, 2, 3,* … tree species in plot *p*

[2] This may be accomplished through a variety of methods such as, but not limited to, tagging of trees, identification of trees using bearing and range from the plot centre, mapping of trees in the sample plot, remote sensing of trees in the sample plot.

[3] However, this does not preclude the possibility of counting the dead tree in the dead wood pool.

p	=	*1, 2, 3, …* sample plots in stratum *i*
i	=	*1, 2, 3, …* tree biomass estimation strata within the project boundary
t	=	*1, 2, 3, …* years counted from the start of the A/R CDM project activity

40. Change in tree biomass in plot *p* in stratum *i* is estimated as follows:

$$\Delta B_{TREE,p,i,(t_1,t_2)} = \sum_j \sum_l \Delta B_{TREE,l,j,p,i(t_1,t_2)} \quad \text{Equation (17)}$$

Where:

$\Delta B_{TREE,p,i,(t_1,t_2)}$	=	Change in tree biomass in sample plot *p* of stratum *i* between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m.
$\Delta B_{TREE,l,j,p,i(t_1,t_2)}$	=	Change in biomass of tree *l* of species *j* in sample plot *p* of stratum *i* between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m.
l	=	*1, 2, 3, …* trees of species *j* in plot *p*
j	=	*1, 2, 3, …* tree species in plot *p*
p	=	*1, 2, 3, …* sample plots in stratum *i*
i	=	*1, 2, 3, …* tree biomass estimation strata within the project boundary
t	=	*1, 2, 3, …* years counted from the start of the A/R CDM project activity

41. Change in tree biomass per hectare in plot *p* in stratum *i* is estimated as follows:

$$\Delta b_{TREE,p,i,(t_1,t_2)} = \frac{\Delta B_{TREE,p,i,(t_1,t_2)}}{A_{p,i}} \quad \text{Equation (18)}$$

Where:

$\Delta b_{TREE,p,i,(t_1,t_2)}$	=	Change in tree biomass per hectare in sample plot *p* of stratum *i* between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m. ha^{-1}
$\Delta B_{TREE,p,i,(t_1,t_2)}$	=	Change in tree biomass in sample plot *p* of stratum *i* between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m.
$A_{p,i}$	=	Area of sample plot *p* in stratum *i*; ha
p	=	*1, 2, 3, …* sample plots in stratum *i*

i	=	*1, 2, 3, …* tree biomass estimation strata within the project boundary
t	=	*1, 2, 3, …* years counted from the start of the A/R CDM project activity

42. Mean change in tree biomass per hectare in stratum *i* and variance of the change in tree biomass per hectare in the stratum are estimated as follows:

$$\Delta b_{TREE,i,(t_1,t_2)} = \frac{\sum_p \Delta b_{TREE,p,i,(t_1,t_2)}}{n_i} \quad \text{Equation (19)}$$

$$s_{\Delta,i}^2 = \frac{n_i \times \sum_{p=1}^{n_i} \Delta b_{TREE,p,i,(t_1,t_2)}^2 - \left(\sum_{p=1}^{n_i} \Delta b_{TREE,p,i,(t_1,t_2)}\right)^2}{n_i \times (n_i - 1)} \quad \text{Equation (20)}$$

Where:

$\Delta b_{TREE,i,(t_1,t_2)}$	=	Mean change in tree biomass per hectare in stratum *i* between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m. ha^{-1}
$\Delta b_{TREE,p,i,(t_1,t_2)}$	=	Tree biomass per hectare in sample plot *p* in stratum *i* between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m. ha^{-1}
n_1	=	Number of sample plots in stratum *i*
$s_{\Delta,i}^2$	=	Variance of change in tree biomass per hectare in stratum *i* between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; (t d.m. $ha^{-1})^2$
p	=	*1, 2, 3, …* sample plots in stratum *i*
i	=	*1, 2, 3, …* tree biomass estimation strata within the project boundary
t	=	1, 2, 3, … years counted from the start of the A/R CDM project activity

43. Mean change in tree biomass per hectare within the project boundary and its variance are estimated as follows:

$$\Delta b_{TREE,(t_1,t_2)} = \sum_{i=1}^{M} w_i \times \Delta b_{TREE,i,(t_1,t_2)} \quad \text{Equation (21)}$$

$$s_{\Delta b_{TREE}}^2 = \sum_{i=1}^{M} w_i^2 \times \frac{s_{\Delta,i}^2}{n_i} \quad \text{Equation (22)}$$

Where:

$\Delta b_{TREE,(t_1,t_2)}$	=	Mean change in tree biomass per hectare within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m. ha^{-1}
w_i	=	Ratio of the area of stratum *i* to the sum of areas of biomass estimation strata; dimensionless
$\Delta b_{TREE,i,(t_1,t_2)}$	=	Mean change in tree biomass per hectare in stratum *i* between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m. ha^{-1}
$s^2_{\Delta b_{TREE}}$	=	Variance of mean change in tree biomass per hectare within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; (t d.m. ha^{-1})^2
$s^2_{\Delta,i}$	=	Variance of change in tree biomass per hectare in stratum *i* between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; (t d.m. ha^{-1})^2
n_i	=	Number of sample plots in stratum *i*
M	=	Number of tree biomass estimation strata within the project boundary
i	=	*1, 2, 3,* … tree biomass estimation strata within the project boundary
t	=	1, 2, 3, … years counted from the start of the A/R CDM project activity

44. Uncertainty of the mean change in tree biomass per hectare within the project boundary is estimated as:

$$u_{\Delta b_{TREE}} = \frac{t_{VAL} \times s_{\Delta b_{TREE}}}{\Delta b_{TREE,(t_1,t_2)}} \quad \text{Equation (23)}$$

Where:

$u_{\Delta b_{TREE}}$	=	Uncertainty of the mean change in tree biomass per hectare within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2%
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%. For example Two-sided Student’s *t*-value for a probability value of 10% (which implies a 90% confidence level) and 45 degrees of freedom can be obtained in Excel spreadsheet as “=TINV(0.10,45)”[4] which returns a value of 1.6794

[4] In EXCEL 2010, TINV has been replaced by T.INV.

$s_{\Delta b_{TREE}}$	=	Square root of the variance of mean change in tree biomass per hectare within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2 (i.e. the standard error of the mean); t d.m. ha^{-1}
$\Delta b_{TREE,(t_1,t_2)}$	=	Mean change in tree biomass per hectare within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m. ha^{-1}

45. Change in tree biomass within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2 is estimated as follows:

$$\Delta B_{TREE,(t_1,t_2)} = A \times \Delta b_{TREE,(t_1,t_2)} \quad \text{Equation (24)}$$

Where:

$\Delta B_{TREE,(t_1,t_2)}$	=	Change in tree biomass within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m.
A	=	Sum of areas of the biomass estimation strata within the project boundary; ha
$\Delta b_{TREE,(t_1,t_2)}$	=	Mean change in tree biomass per hectare within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m. ha^{-1}
t	=	1, 2, 3, … years counted from the start of the A/R CDM project activity

46. Change in carbon stock in tree biomass within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2 is estimated as follows:

$$\Delta C_{TREE,(t_1,t_2)} = \frac{44}{12} \times \Delta B_{TREE,(t_1,t_2)} \times CF_{TREE} \quad \text{Equation (25)}$$

Where:

$\Delta C_{TREE,(t_1,t_2)}$	=	Change in carbon stock in tree biomass within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t CO_2-e
$\Delta B_{TREE,(t_1,t_2)}$	=	Change in tree biomass within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t d.m.
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

47. Rate of change of carbon stock in trees between the years t_2 and t_1 is estimated as follows:

$$dC_{TREE,(t_1,t_2)} = \frac{\Delta C_{TREE,(t_1,t_2)}}{T}$$ Equation (26)

Where:

$dC_{TREE,(t_1,t_2)}$	=	Rate of change in carbon stock in tree biomass within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t CO_2-e yr^{-1}
$\Delta C_{TREE,(t_1,t_2)}$	=	Change in carbon stock in tree biomass within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; t CO_2-e
T	=	Time elapsed between two successive verifications ($T = t_2 - t_1$); yr. If the two successive verifications of carbon stock in trees are carried out at different points of time in year t_2 and t_1, (e.g. in the month of April in year t_1 and in the month of September in year t_2), then a fractional value is assigned to T
t	=	1, 2, 3, … years counted from the start of the A/R CDM project activity

48. Carbon stock in tree biomass within the project boundary at a point of time in year t falling between t_1 and t_2 is estimated as follows:

$$C_{TREE,t} = C_{TREE,t-1} + dC_{TREE,(t_1,t_2)} \times 1 year$$ Equation (27)

Where:

$C_{TREE,t}$	=	Carbons stock in tree biomass within the project boundary at a point of time in year t; t CO_2-e
$C_{TREE,t-1}$	=	Carbons stock in tree biomass within the project boundary at a point of time in year $t - 1$; t CO_2-e
$dC_{TREE,(t_1,t_2)}$	=	Rate of change in carbon stock in tree biomass within the project boundary during the period between a point of time in year t_1 and a point of time in year t_2; t CO_2-e yr^{-1}
t	=	1, 2, 3, … years counted from the start of the A/R CDM project activity

9.3. Baseline default method

49. This method is applicable only for estimation of carbon stock in trees in the baseline when:

(a) Stock change cannot be applied for lack of data; or

(b) The mean tree crown cover in the baseline 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. (for example: if the threshold crown cover is 30%, then the mean tree crown cover is 6% or less).

50. Change in carbon stock in trees in the baseline is estimated as follows:

$$\Delta C_{TREE\_BSL,i} = \frac{44}{12} \times CF_{TREE\_BSL} \times \Delta B_{FOREST} \times \left(1 + R_{TREE\_BSL}\right) \times CC_{TREE\_BSL,i} \times A_{BSL,i}$$ Equation (28)

$$\Delta C_{TREE\_BSL} = \sum_{i=1}^{M} \Delta C_{TREE\_BSL,i}$$ Equation (29)

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_BSL}	=	Carbon fraction of tree biomass in the baseline; 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}
R_{TREE_BSL}	=	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
$A_{BSL,i}$	=	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
i	=	*1, 2, 3, …* tree biomass estimation strata within the project boundary

10. Correction for large maximum allowable relative error

51. The maximum allowable relative error of the mean tree biomass is calculated using the following equations:

(a) Stock change method;

$$RE_{max} = u_{b_{TREE,t}}$$ Equation (30)

(b) Increment method[5]

$$RE_{max} = \frac{u_{\Delta b_{TREE,t}}}{\sqrt{2}} \quad \text{Equation (31)}$$

Where:

RE_{max}	=	Maximum relative error, %
$u_{b_{TREE,t}}$	=	Uncertainty of the mean tree carbon per hectare within the project boundary at time *t*; %
$u_{\Delta b_{TREE,t}}$	=	Uncertainty of the mean change in tree biomass per hectare within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2
t	=	1, 2, 3, … years counted from the start of the A/R CDM project activity

52. If RE_{max} is greater than 10%, then the project proponent may decide to either:

(a) Install additional sample plots; or

(b) Accept a deduction in the estimated change in carbon stocks.

53. To install additional sample plots, the number of sample plots for the required allowable relative margin of error of the mean may be calculated using the tool "Calculation of the number of sample plots for measurements within A/R CDM project activities" using the stratum standard deviations equal to square root of the stratum variances estimated in Equation (8) and Equation (20) above.

54. To accept a deduction use the following equations:

(a) If $\Delta C_{TREE,(t_1,t_2)} \geq 0$ then:

$$\Delta C_{TREE,t} = \Delta C_{TREE(t_1,t_2)} \times (1 - DR) \quad \text{Equation (32)}$$

(b) If $\Delta C_{TREE,(t_1,t_2)} < 0$ then:

$$\Delta C_{TREE,t} = \Delta C_{TREE(t_1,t_2)} \times (1 + DR) \quad \text{Equation (33)}$$

5 The actual relative error for the increment method is calculated as the root mean square sum of the errors in the two years. This is strictly not comparable to the error in the stock. The factor, 1/√2, is an approximation that assumes that the relative errors in both stock measurements are roughly the same, and the stocks are roughly the same.

Where:

$\Delta C_{TREE(t_1,t_2)}$	=	Change in carbon stock in tree biomass within the project boundary between the earlier verification carried out at time t_1 and the later verification carried out at time t_2; corrected for large maximum relative error, t CO_2-e
t	=	1, 2, 3, … years counted from the start of the A/R CDM project activity

and *DR* is obtained from the following table:[6]

Table 8. Deduction rates

Relative margin of error	**Deduction Rate (DR)**
Less than or equal to 10%	0%
Greater than 10 % but less than or equal to 30%	6%
Greater than 30% but less than or equal to 50%	12%
Greater than 50% but less than or equal to 100%	21%
Greater than 100%	37%

11. Estimation of C stock and change in C stock in shrubs

11.1. Estimation of carbon stock in shrubs

55. Carbon stock in shrub biomass is estimated for each shrub biomass stratum delineated on the basis of shrub crown cover. Once the area within the project boundary has been stratified on the basis of shrub crown cover, carbon stock in shrub biomass within the project boundary at a given point of time in year *t* is calculated as:

$$C_{SHRUB,t} = \frac{44}{12} \times CF_S \times (1 + R_S) \times \sum_i A_{SHRUB,i,t} \times B_{SHRUB,i,t} \qquad \text{Equation (34)}$$

Where:

$C_{SHRUB,t}$	=	Carbon stock in shrub biomass 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 $(t.d.m.)^{-1}$ IPCC default value of 0.47 t C $(t.d.m.)^{-1}$ is used
R_S	=	Root-shoot ratio for shrubs; dimensionless

[6] Adapted from Appendix III of 20/CMP.1.

$A_{SHRUB,i,t}$	=	Area of shrub biomass stratum *i* at a given point of time in year *t*; ha
$B_{SHRUB,i,t}$	=	Shrub biomass per hectare in shrub biomass stratum *i* at a given point of time in year *t*; t d.m. ha^{-1}
i	=	*1, 2, 3, …* shrub biomass strata delineated on the basis of shrub crown cover
t	=	*1, 2, 3, …* years counted from the start of the A/R CDM project activity

56. Shrub biomass per hectare ($B_{SHRUB,i,t}$) is estimated as follows:

(a) For those areas where the shrub crown cover is less than 5%, the shrub biomass per hectare is considered negligible and hence accounted as zero;

(b) For those areas where the shrub crown cover is 5% or more, shrub biomass per hectare is estimated as follows:

$$B_{SHRUB,i,t} = BDR_{SF} \times B_{FOREST} \times CC_{SHRUB,i,t}$$ Equation (35)

Where:

$B_{SHRUB,i,t}$	=	Shrub biomass per hectare in shrub biomass stratum *i*, at a given point of time in year *t*; t d.m. ha^{-1}
BDR_{SF}	=	Ratio of shrub biomass per hectare in land having a shrub crown cover of 1.0 and default above-ground biomass content per hectare in forest in the region/country where the A/R CDM project is located; dimensionless
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}
$CC_{SHRUB,i,t}$	=	Crown cover of shrubs in shrub biomass stratum *i* at a given point of time in year *t* expressed as a fraction (e.g. 10% crown cover implies $CC_{SHRUB,i,t}$ = 0.10); dimensionless
t	=	1, 2, 3, … years counted from the start of the A/R CDM project activity

11.2. Estimation of change in carbon stock in shrubs

57. The rate of change of shrub biomass over a period of time is estimated as follows:

$$dC_{SHRUB,(t_1,t_2)} = \frac{C_{SHRUB,t_2} - C_{SHRUB,t_1}}{T}$$ Equation (36)

Where:

$dC_{SHRUB,(t_1,t_2)}$	=	Rate of change in carbon stock in shrub biomass within the project boundary during the period between a point of time in year t_1 and a point of time in year t_2; t CO_2-e yr^{-1}
C_{SHRUB,t_2}	=	Carbon stock in shrub biomass within the project boundary at a point of time in year t_2; t CO_2-e
C_{SHRUB,t_1}	=	Carbon stock in shrub biomass within the project boundary at a point of time in year t_1; t CO_2-e
T		Time elapsed between two successive estimations ($T=t_2 - t_1$); yr
t		1, 2, 3, … years counted from the start of the A/R CDM project activity

58. For the first verification, the variable C_{SHRUB,t_1} in Equation (36) is assigned the value of carbon stock in the shrub biomass at the start of the A/R CDM project activity, that is: $C_{SHRUB,t_1} = C_{SHRUB\_BSL}$ for the first verification, where t_1 = 1 and t_2 = year of the first verification.

59. Change in carbon stock in shrub biomass within the project boundary in year t ($t_1 \leq t \leq t_2$) is calculated as follows:

$$\Delta C_{SHRUB,t} = dC_{SHRUB,(t_1,t_2)} \times 1\ year \text{ for } t_1 \leq t \leq t_2 \qquad \text{Equation (37)}$$

Where:

$\Delta C_{SHRUB,t}$	=	Change in carbon stock in shrub biomass within the project boundary in year t; t CO_2-e
$dC_{SHRUB,(t_1,t_2)}$	=	Rate of change in carbon stock in shrub biomass within the project boundary during the period between a point of time in year t_1 and a point of time in year t_2; t CO_2-e yr^{-1}
t	=	1, 2, 3, … years counted from the start of the A/R CDM project activity

12. Data and parameters used in the tool

60. The following tables describe the data and parameters used in this tool. The guidelines contained in these tables regarding selection of data sources and procedures to be followed in measurement, where applicable, should be treated as an integral part of this tool.

12.1. Data and parameters not measured

Data / Parameter table 1.

Data / Parameter:	$BEF_{2,j}$
Data unit:	Dimensionless
Description:	Biomass expansion factor for conversion of stem biomass to above-ground biomass for tree species *j*
Source of data:	Values from Table 3A.1.10 of IPCC GPG-LULUCF 2003 are used unless transparent and verifiable information can be provided to justify different values[7]
Measurement procedures (if any):	-
Monitoring frequency:	-
QA/QC procedures:	-
Any comment:	*BEFs* in IPCC literature and national inventory are usually applicable to closed canopy forest. If applied to individual trees growing in an open field the selected BEF is increased by 30% This Data/Parameter is used in Equation (1)

Data / Parameter table 2.

Data / Parameter:	BDR_{SF}
Data unit:	Dimensionless
Description:	Ratio of biomass per hectare in land having a shrub crown cover of 1.0 (i.e. 100%) and the default above-ground biomass content in forest in the region/country where the A/R CDM project is located
Source of data:	A default value of 0.10 should be used unless transparent and verifiable information can be provided to justify a different value
Measurement procedures (if any):	-
Monitoring frequency:	-
QA/QC procedures:	-
Any comment:	This Data/Parameter is used in Equation (35)

[7] Although the *BEFs* in Table 3A.1.10 apply to biomass, the dimensionless factors can be equally applied for wood volume expansions.

Data / Parameter table 3.

Data / Parameter:	B_{FOREST}
Data unit:	t d.m. ha^{-1}
Description:	Default above-ground biomass content in forest in the region/country where the A/R CDM project is located
Source of data:	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
Measurement procedures (if any):	
Monitoring frequency:	
QA/QC procedures:	
Any comment:	This Data/Parameter is used in Equations (3) and (35)

Data / Parameter table 4.

Data / Parameter:	ΔB_{FOREST}
Data unit:	t d.m. ha^{-1} yr^{-1}
Description:	Default average annual increment in above-ground biomass in forest in the region/country where the A/R CDM project is located
Source of data:	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.
Measurement procedures (if any):	-
Monitoring frequency:	-
QA/QC procedures:	-

Any comment:	(a) 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 20th year from the start of the CDM project activity, unless transparent and verifiable information can be provided to justify a different year; (b) When land is subjected to periodic slash-and-burn practices in the baseline, the average tree biomass is constant, and hence value of this parameter is set equal to zero. This Data/Parameter is used in Equation (28)

Data / Parameter table 5.

Data / Parameter:	D_j
Data unit:	t d.m. m^{-3}
Description:	Density (overbark) of tree stem for tree species *j*

Source of data:	Value is taken from published literature, or is estimated as follows: $D_j = D_{wood,j} * (1 - \%Bark_{volume}) + D_{bark,j} * \%Bark_{volume}$ Where: $\mathbf{D_j}$ = Density (overbark) of tree species *j*; t d.m. m^{-3} $\mathbf{D_{wood,j}}$ = Basic wood density of tree species *j*: t d.m. m^{-3}. Values from Table 3A.1.9 of IPCC GPG-LULUCF 2003 are used unless transparent and verifiable information can be provided to justify different values $\%\mathbf{Bark_{volume}}$ = Volume of tree trunk that is made of bark; percent. Default value of 15% is used[8] unless transparent and verifiable information can be provided to justify a different value $\mathbf{D_{bark,j}}$ = Density of bark of species *j*; t d.m. m-3. Default value of 0.4 is used[9] unless transparent and verifiable information can be provided to justify a different value
Measurement procedures (if any):	-
Monitoring frequency:	-
QA/QC procedures:	-
Any comment:	This Data Parameter is used in Equation (1)

Data / Parameter table 6.

Data / Parameter:	R_j
Data unit:	Dimensionless
Description:	Root-shoot ratio for tree species *j*

[8] IPCC Good Practice Guidance for LULUCF (page 3.29)

[9] Quilhó, T. & Helena Pereira, H. 2001. Within And Between-Tree Variation Of Bark Content And Wood Density Of Eucalyptus Globulus In Commercial Plantations. IAWA Journal, Vol. 22 (3), 2001: 255– 265

Source of data:	The value of R_j is calculated as R = exp[-1.085+0.9256*ln(A)]/A, where A is above-ground biomass content (t d.m. ha^{-1}) [Table 4.A.4 of IPCC GPG-LULUCF 2003] unless transparent and verifiable information can be provided to justify different values. If the living trees in a sample plot have grown from 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 verification
Measurement procedures (if any):	-
Monitoring frequency:	-
QA/QC procedures:	-
Any comment:	This Data/Parameter is used in Equations (1) and (2)

Data / Parameter table 7.

Data / Parameter:	R_S
Data unit:	Dimensionless
Description:	Root-shoot ratio for shrubs
Source of data:	The value of RS shall be 0.40 [Table 4.4 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories] unless transparent and verifiable information can be provided to justify different values
Measurement procedures (if any):	-
Monitoring frequency:	-
QA/QC procedures:	-
Any comment:	This Data/Parameter is used in Equation (34)

12.2. Data and parameters measured

Data / Parameter table 8.

Data / Parameter:	$A_{p,i}$
Data unit:	Ha
Description:	Area of sample p in stratum *i*
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:	Every five years since the year of the initial 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
Any comment:	Sample plot location is registered with a GPS and marked on the project map. This Data /Parameter is used in Equations (6) and (18)

Data / Parameter table 9.

Data / Parameter:	$A_{SHRUB,i,t}$
Data unit:	ha
Description:	Area of shrub biomass stratum i at a given point of time in year *t*
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:	Every five years since the year of the initial 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
Any comment:	This Data/Parameter is used in Equation (34)

Data / Parameter table 10.

Data / Parameter:	$CC_{SHRUB,i,t}$
Data unit:	Dimensionless
Description:	Crown cover of shrubs in shrub biomass stratum *i* at a given point of time in year *t*
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:	Every five years since the year of the initial 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
Any comment:	(a) When land is subjected to periodic slash-and-burn practices in the baseline, an average shrub crown cover equal to default value of 0.5 is used in Equation (35) unless transparent and verifiable information can be provided to justify a different value; (b) Ex ante estimation of shrub crown cover at a time other than at the start of the project is carried out with the following considerations in view: (i) Shrub crown cover is assumed to remain at the pre-project level unless transparent and verifiable information can be provided to justify a different rate of change; (ii) When land is abandoned, shrubs may encroach such land and shrub crown cover may reach the maximum value of 1.0 over a period of 20 years from the year in which the land is abandoned. If the year in which the land is abandoned is not known, then an average crown cover of 0.50 is assumed at the start of the project. This Data/Parameter is used in Equation (35)

Data / Parameter table 11.

Data / Parameter:	$CC_{TREE\_BSL,i}$
Data unit:	Dimensionless
Description:	Crown cover of trees in the baseline, in baseline stratum *i*, expressed as a fraction (e.g. 10% crown cover implies $CC_{TREE\_BSL,i}$ =0.10)
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:	N/A

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
Any comment:	This Data/Parameter is used in equations (3), (4), (28) and (29)

Data / Parameter table 12.

Data / Parameter:	$V_{TREE,j,p,i,t}$
Data unit:	m3
Description:	Stem volume of trees of species *j* in sample plot p of stratum *i* at a point of time in year *t* calculated using a volume table or volume equation
Source of data:	Field measurements of tree parameters (such as *DBH*, *H*, etc.) measured in sample plot *p* of stratum *i* at a given point of time in year *t*

<table>
<tr><td>Measurement procedures (if any):</td><td>A volume table or volume equation is a table or an equation that predicts tree stem volume on the basis of one or more measurements of a tree.

Where applied volume equations result in underbark volume (i.e. commercial volume, rather than gross stem volume) a correction factor is required to estimate tree volume. Where applied volume equations calculate stem volume, this correction factor is not needed and the below equation should not be used:

$V_{TREE,j,p,i,t} = V_{TREE,underbark,j,p,i,t} \ x \ Corr_{underbark}$

Where:
$V_{TREE,j,p,i,t}$ = Stem volume of trees of species j in sample plot p of stratum i at a point of time in year t, estimated by using the tree dimension(s) as entry data into a volume table or volume equation; m3
$V_{TREE,underbark,j,p,i,t}$ = Under bark volume of trees of species j in sample plot p of stratum i at a point of time in year t, estimated by using the tree dimension(s) as entry data into a volume table or volume equation; m3 to justify different values
$Corr_{underbark}$ = Factor to correct underbark volume to stem volume.
Default value of $\frac{1}{0.85}$ is used[10] unless transparent and verifiable information can be provided to justify a different value
j = 1, 2, 3, … tree species in plot p
p = 1, 2, 3, … sample plots in stratum i
i = 1, 2, 3, … tree biomass estimation strata within the project boundary
t = 1, 2, 3, … years counted from the start of the A/R CDM project activity</td></tr>
<tr><td>Monitoring frequency:</td><td>Every five years since the year of the initial verification</td></tr>
</table>

[10] A default of 15% bark volume is assumed in IPCC Good Practice Guidance for LULUCF (page 3.29)

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
Any comment:	-

Data / Parameter table 13.

Data / Parameter:	$x1_{p,i,t}, x2_{p,i,t}, x3_{p,i,t},...$
Data unit:	Unit of parameter such as length (cm)
Description:	Often tree parameters such as tree height and diameter at breast height of the tree, but other tree parameters could be used (e.g. basal diameter, root-collar diameter, basal area, etc.) that are applicable for the model or data source used
Source of data:	Field measurements in sample plots. For ex ante estimations, values should be estimated using a growth curve, a growth model, or a yield table that gives the expected tree dimensions as a function of tree age
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:	Every five years since the year of the initial 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
Any comment:	This Data/Parameter is used in Equation (2)

Data / Parameter table 14.

Data / Parameter:	T
Data unit:	Year
Description:	Time period elapsed between two successive estimations of carbon stock in trees and shrubs
Source of data:	Recorded time
Measurement procedures (if any):	N/A
Monitoring frequency:	-

QA/QC procedures:	-
Any comment:	If the two successive estimations of carbon stock in trees are carried out at different points of time in year t_2 and t1, (e.g. in the month of April in year t_1 and in the month of September in year t_2), then a fractional value is assigned to *T*. This Data /Parameter is used in equations (14), (26) and (36)

Data / Parameter table 15.

Data / Parameter:	$f_j(x1_{p,i,t}, x2_{p,i,t}, x3_{p,i,t},...)$
Data unit:	t d.m.
Description:	Function relating measured tree dimensions (x1, x2, x3, …) to above-ground tree biomass
Source of data:	For ex ante estimation the allometric equation applicable 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); (i) National data (e.g. from national forest inventory or national GHG inventory); (ii) Data from neighbouring countries with similar conditions; (iii) Globally applicable data. 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"
Measurement procedures (if any):	-
Monitoring frequency:	-
QA/QC procedures:	-
Any comment:	-

Data / Parameter table 16.

Data / Parameter:	Volume table or equation
Data unit:	m3
Description:	Volume table or volume equation is a table or an equation that predicts tree stem volume on the basis of one or more measurements of a tree (e.g. *DBH* and/or tree height)

Source of data:	For ex ante estimation table or equation applicable 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); (i) National data (e.g. from national forest inventory or national GHG inventory); (ii) Data from neighbouring countries with similar conditions; (iii) Globally applicable data. For ex post estimation, the volume table or 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"
Measurement procedures (if any):	-
Monitoring frequency:	-
QA/QC procedures:	-
Any comment:	-

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Document information

Version	*Date*	*Description*
03.0.0	08 November 2012	A/R WG 37, Annex 3 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.

Decision Class: Regulatory
Document Type: Tool
Business Function: Methodology
Keywords: carbon pools, biomass