GLOBAL CARBON COUNCIL

Driving Climate Actions

GCC Tool for estimation of carbon stocks and change in carbon stocks of trees and shrubs in NBS project activities

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CONTENTS

1. GCC NBS Methodologies and Tools

1. Global Carbon Council (GCC) is MENA region's first and only voluntary carbon offsetting and sustainable development program that contributes to a vision of sustainable and low carbon economy of the region and catalyses climate actions on the ground. Refer to www.globalcarboncouncil.com for details.

2. GCC Nature-based Solutions (NBS) methodologies and tools allow for conservative estimation of GHG emission reductions and changes in carbon stocks resulting from the NbS project activity.

2. Source of this Tool

3. This tool updates and revises the approach contained in the CDM A/R Tool "Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities" Version 04.2 and replaces it for use in Nature-based Solution (NBS) projects seeking registration/registered under the GCC.

3. Scope, Applicability, and Entry into force

3.1. Scope

4. This tool can be used for estimation of carbon stock and change in carbon stock in living biomass of trees and shrubs in NBS project activity. The tool is applicable for:

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

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

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

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

3.2. Applicability Conditions

6. This tool has no internal applicability conditions. However, any methodology implementing the tool shall define the targeted precision for carbon stocks to be estimated.

3.3. Entry into force

7. The date of entry into force of this version of the methodology is DD MM 2024.

4. Definitions

8. The definitions contained in the following documents shall apply:[1]

(a) GCC Program Definitions;

(b) IPCC (2006). Guidelines for National Greenhouse Gas Inventories;

(c) 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

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

(a) **Confidence level** indicates the probability with which the estimation of the location of a statistical parameter (e.g., the mean) in a sample survey is also true for the entire population. A 0% confidence level means that it is impossible that the estimated parameter represents the entire population. A 100% confidence level means that it is certain that the estimated parameter represents the entire population, such certainty may be achieved only by sampling all elements contained in the population.

(b) **Confidence interval** for a population parameter (e.g., the mean) is a random interval, calculated from the sample, that contains the parameter with a specified confidence level. For example, a 90% confidence interval for the mean is a random interval that contains it with a probability of 0.90.

(c) **Conservative use of a parameter** - refers to the use of a value that, when applied in calculations, is more likely to result in underestimation rather than overestimation of GCC project-level GHG emission reduction and/or removal.

(d) **Uncertainty** – is the half-width of the (e.g., 90%) confidence interval divided by the mean value of an estimated parameter, expressed as a percentage.

Example: The mean value of tree biomass per hectare is estimated at 50 t ha^{-1} from a sample of size 16. Sample standard deviation is 20 t ha^{-1} . The estimated standard error of the mean (SEM) is $\frac{20}{\sqrt{16}} = 5$ t ha^{-1}. Two-sided Student's t-value for a confidence level of 90 % and degrees of freedom equal to 16-1=15 is obtained by means of Excel function T.INV.2T(probability, deg_freedom) which returns two-sided Student's t-value for probability equal to (100%-confidence level) at defined number of degrees of freedom (e.g., T.INV.2T(0.1, 15)= 1.753). Therefore, the half-width of the 90% confidence interval of SEM equals 1.753 * 5 t ha^{-1}= 8.765 t ha^{-1}. This implies that the estimated mean has an uncertainty of 8.765/50 = 17.53%.

Note: In this tool only sampling uncertainty is assessed and controlled. Uncertainty in values obtained from direct measurement (e.g. measured diameter of a tree) or values derived from models is not quantified here. This type of uncertainty should be managed through application of appropriate quality assurance and quality control (QA/QC) methods.

(e) **Plant species** - refers to a distinct group of plants that share common biological characteristics and can interbreed to produce fertile offspring, can also refer to a

[1] These documents are available online at the following URLs:
(a) <http://www.globalcarboncouncil.com/resource-centre/>;
(b) https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html;
(c) https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html .

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

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

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

(h) **Plot biomass** - refers to tree/shrub biomass per hectare in a plot;

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

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

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

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

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

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

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

5. Assumptions

12. This tool applies the following assumptions:

(a) The area of each stratum within the project boundary is approximately known (ex-ante) or measured (ex-post);

(b) The variability of biomass stock and stock changes is expressed as variance in the stratum. The approximate value of the ex-ante variance of biomass stock in each stratum is either known from existing data applicable to the project area or existing data related to a similar area, or is estimated on the basis of a preliminary sample or an expert judgement. The ex-post variance is calculated using data collected during monitoring.

(c) All parameters used in calculation of plot level biomass stock (e.g. biomass expansion factors, root-shoot ratios) are fixed constants.

(d) All models used for calculation of plot level biomass stock (e.g. volume tables or equations, allometric equations) are exact.

6. Parameters determined by the tool

13. This tool provides procedures to determine the parameters listed in Table 1.

Table 1. Parameters determined by the tool

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

7. Stratification

14. The project area is stratified based on the variability of the biomass stock being estimated, and approximate area of each stratum is determined. If the biomass stock being estimated is sum of biomass stocks in more than one pool, then stratification is carried out on the basis of the variability of the biomass stock of the dominant pool (i.e. the pool containing the largest amount of biomass stock).

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

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

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

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

(c) The pre-project trees are not inventoried along with the project trees in monitoring of carbon stocks, but their continued existence, consistent with the baseline scenario, is monitored throughout the crediting period of the project activity.

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

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

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

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

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

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

(f) Land is subjected to periodic cycles (e.g. slash-and-burn, or clearing-regrowing cycles) so that the biomass oscillates between a minimum and a maximum value in the baseline;

(g) Conditions (a), (b), and (c) under paragraph 16 apply.

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

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

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

(a) Difference of two independent stock estimations;

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

(c) Estimation by proportionate crown cover;

(d) Demonstration of “no-decrease”.

9.1. Difference of two independent stock estimations

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

Note. This is method is efficient when the correlation between the plot biomass values on the two occasions is absent or weak (e.g. when there has been harvest or disturbance in a stratum after the first estimation, resulting in spatial re-distribution of tree biomass in the stratum).

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

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

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

Where:

ΔC_{TREE}	=	Change in carbon stock in trees during the period between two points of time t_1 and t_2; t CO_2e

C_{TREE,t_1}	=	Carbon stock in trees as estimated at time t_1; t CO_2e Note 1. At the first verification C_{TREE,t_1} is set equal to the carbon stock in the pre-project tree biomass $(i.e. C_{TREE,t_1} = C_{TREE\_BSL})$. However, this may be set equal to zero, if all the conditions specified under paragraph 16 are met. Note 2. Even if C_{TREE,t_1} was made conservative at the time of previous verification, it is the estimated (undiscounted) value of C_{TREE,t_1} that is used here.
C_{TREE,t_2}	=	Carbon stock in trees as estimated at time t_2; t CO_2e
$u_{\Delta C}$	=	Uncertainty in ΔC_{TREE}
u_1, u_2	=	Uncertainties in C_{TREE,t_1} and C_{TREE,t_2} respectively

21. Carbon stock in trees at a point of time is estimated by using one of the applicable methods provided in section 11.

22. If $u_{\Delta C}$ estimated from Equation (2) is greater than 20 per cent, ΔC_{TREE} is made conservative by applying uncertainty discount according to the procedure provided in Appendix 2.

9.2. Direct estimation of change by re-measurement of sample plots

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

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

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

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

$$\Delta B_{TREE} = A * \Delta b_{TREE}$$ *Equation (4)*

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

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

Where:

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

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

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

Equation (7)

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

Equation (8)

Where:

$\Delta b_{TREE,i}$	=	Mean change in tree biomass per hectare in stratum *i*; t d.m. ha^{-1}
$\Delta b_{TREE,p,i}$	=	Change in tree biomass per hectare in plot *p* in stratum *i*; t d.m. ha^{-1}
$s^2_{\Delta,i}$	=	Variance of mean change in tree biomass per hectare in stratum *i*; (t d.m. ha^{-1})^2
n_i	=	Number of sample plots, in stratum *i*, in which tree biomass was re-measured

26. If $u_{\Delta C}$ estimated from Equation (6) is greater than 20 per cent, ΔC_{TREE} is made conservative by applying uncertainty discount according to the procedure provided in Appendix 2.

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

9.3. Estimation by proportionate crown cover

28. This method is applicable only in ex-ante estimation of change in carbon stock in trees in the baseline where the mean pre-project tree crown cover is less than 6 per cent.

29. 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)*

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

Where:

ΔC_{TREE_BSL}	=	Mean annual change in carbon stock in trees in the baseline; t CO_2e yr^{-1}
$\Delta C_{TREE\_BSL,i}$	=	Mean annual change in carbon stock in trees in the baseline, in baseline stratum *i*; t CO_2e yr^{-1}
CF_{TREE}	=	Carbon fraction of tree biomass; t C $(t.d.m.)^{-1}$. A default value of 0.47 t C $(t.d.m.)^{-1}$ is used unless transparent and verifiable information can be provided to justify a different value.
Δb_{FOREST}	=	Default mean annual increment of above-ground biomass in forest in the region or country where the NBS project activity is located; t d.m. ha^{-1} yr^{-1}. Values of Δb_{FOREST} are taken from Table 4.9 (p. 4.34) of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* unless transparent and verifiable information can be provided to justify different values. Note. Tree biomass may reach a steady state in which biomass growth becomes zero or insignificant, either because of biological maturity of trees or because the rate of anthropogenic biomass extraction from the area is equal to the rate of biomass growth. Therefore, this parameter should be taken to be zero after the year in which tree biomass in the baseline reaches a steady state. The year in which tree biomass in the baseline reaches a steady state is taken to be the 20th year from the start of the NBS project activity, unless transparent and verifiable information can be provided to justify a different year.

R_{TREE}	=	Root-shoot ratio for the trees in the baseline; dimensionless. A default value of 0.25 is used unless transparent and verifiable information can be provided to justify a different value.
$CC_{TREE\_BSL,i}$	=	Crown cover of trees in the baseline, in baseline stratum *i*, at the start of the NBS project activity, expressed as a fraction (e.g. 10 per cent crown cover implies $CC_{TREE\_BSL,i}$ = 0.10); dimensionless
A_i	=	Area of baseline stratum *i*, delineated on the basis of tree crown cover at the start of the NBS project activity; ha

9.4. Demonstration of "no-decrease"

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

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

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

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

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

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

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

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

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

$$\Delta C_{TREE,t} = \frac{C_{TREE,t_2} - C_{TREE,t_1}}{T} * 1\ year$$

Equation (11)

Where:

$\Delta C_{TREE,t}$	=	Change in carbon stock in trees within the project boundary in year *t*; t CO_2e

C_{TREE,t_2}	=	Carbon stock in trees within the project boundary at time t_2; t CO_2e. Note. Where estimation of carbon stock in tree biomass at time t_2 is carried out by applying different methods in different strata, C_{TREE,t_2} is set equal to the sum of carbon stocks in all the strata in which the project area is divided.
C_{TREE,t_1}	=	Carbon stock in trees within the project boundary at time t_1; t CO_2e. Note. Where estimation of carbon stock in tree biomass at time t_1 is carried out by applying different methods in different strata, C_{TREE,t_1} is set equal to the sum of carbon stocks in all the strata in which the project area is divided.
T	=	Time elapsed between two successive estimations ($T=t_2 - t_1$); yr. Note 1. Value of *T* does not have to be a whole number (e.g. an interval of 4 years and 5 months implies T = 4.417 yr). Note 2. Estimation of change in carbon stock in trees by proportionate crown cover (*see* section 9.3) results in an annual change estimate and hence Equation (11) does not apply under this method.

11. Estimating carbon stock in trees at a point in time

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

(a) Estimation by measurement of sample plots;

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

(c) Estimation by proportionate crown cover;

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

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

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

11.1. Estimation by measurement of sample plots

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

(a) Stratified random sampling;

(b) Double sampling.

11.1.1. Stratified random sampling

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

Note. This method is more efficient when the sample plots are optimally allocated to the strata keeping in view the expected mean tree biomass per hectare and its variability in the strata.

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

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

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

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

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

Where:

C_{TREE}	=	Carbon stock in trees in the tree biomass estimation strata; t CO_2e
CF_{TREE}	=	Carbon fraction of tree biomass; t C (t d.m.)$^{-1}$. A default value of 0.47 is used unless transparent and verifiable information can be provided to justify a different value.
B_{TREE}	=	Tree biomass in the tree biomass estimation strata; t d.m.
A	=	Sum of areas of the tree biomass estimation strata; ha
b_{TREE}	=	Mean tree biomass per hectare in the tree biomass estimation strata; t d.m. ha^{-1}
w_i	=	Ratio of the area of stratum *i* to the sum of areas of tree biomass estimation strata (i.e. $w_i = A_i/A$); dimensionless
$b_{TREE,i}$	=	Mean tree biomass per hectare in stratum *i*; t d.m. ha^{-1}
u_C	=	Uncertainty in C_{TREE}
t_{VAL}	=	Two-sided Student's *t*-value for a confidence level set in methodology implementing this tool and degrees of freedom equal to *n* – *M*, where *n* is total number of sample plots within the tree biomass estimation strata and *M* is the total number of tree biomass estimation strata

s_i^2	=	Variance of tree biomass per hectare across all sample plots in stratum *i*; (t d.m. ha^{-1})^2
n_i	=	Number of sample plots in stratum *i*.

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

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

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

Where:

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

41. If u_C estimated from Equation (15) is greater than 20 per cent, C_{TREE} is made conservative by applying uncertainty discount according to the procedure provided in Appendix 2.

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

11.1.2. Double sampling

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

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

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

<u>Example 1.</u> In a large project area, the spatial distribution of tree biomass was highly heterogeneous, and it was not efficient to delineate tree biomass strata. However, remotely sensed satellite data covering the area was available at a very low cost. An index, namely, Normalized Difference Vegetation Index (NDVI), was constructed from this data which was found to have approximately linear relationship with the per-hectare tree

biomass. A double sampling design was adopted with construction of NDVI in 2000 sample plots and measurement of diameter of all trees in 150 sample plots selected from the 2000 plots using systematic selection with a random start. This double sampling design reduced the variance of the estimated mean by one third. To achieve the same precision by measuring fixed-area plots alone would have required measurement of 300 fix-area sample plots which would have been costlier.

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

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

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

Where:

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

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

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

48. If u_C estimated from Equation (15) is greater than 20 per cent, C_{TREE} is made conservative by applying uncertainty discount according to the procedure provided in Appendix 2.

11.2. Estimation by modelling of tree growth and stand development

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

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

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

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

11.3. Estimation by proportionate crown cover

53. This method is applicable only for estimation of the pre-project carbon stock in tree biomass in the baseline where the mean pre-project tree crown cover is less than 6 per cent.

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

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

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

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

Where:

C_{TREE_BSL}	=	Carbon stock in pre-project tree biomass; t CO_2e
$C_{TREE\_BSL,i}$	=	Carbon stock in pre-project tree biomass in stratum *i*; t CO_2e
CF_{TREE}	=	Carbon fraction of tree biomass; t C (t.d.m.)$^{-1}$. A default value of 0.47 t C (t.d.m.)$^{-1}$ is used.
b_{FOREST}	=	Mean above-ground biomass in forest in the region or country where the NBS project is located; t d.m. ha^{-1} Values of Δb_{FOREST} are taken from Table 4.9 (p. 4.34) of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* 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. Values of R_{TREE} are taken from Table 4.4 (p. 4.18) of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* are used unless transparent and verifiable information can be provided to justify a different value.
$CC_{TREE\_BSL,i}$	=	Crown cover of trees in baseline stratum *i*, at the start of the NBS project activity, expressed as a fraction (e.g. 10 per cent crown cover implies $CC_{TREE\_BSL,i}$ = 0.10); dimensionless
A_i	=	Area of baseline stratum *i*, delineated on the basis of tree crown cover at the start of the NBS project activity; ha

11.4. Updating previous stock by direct estimation of change

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

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

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

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

Where:

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

58. If u_2 estimated from Equation (23) is greater than 20 per cent, C_{TREE,t_2} is made conservative by applying uncertainty discount according to the procedure provided in Appendix 2.

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

59. 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

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

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

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

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

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

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

Where:

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

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

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

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

$$C_{SHRUB,t} = \frac{44}{12} * CF_S * (1 + R_S) * \sum_i A_{SHRUB,i} * b_{SHRUB,i}$$ *Equation (26)*

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

Where:

$C_{SHRUB,t}$	=	Carbon stock in shrubs within the project boundary at a given point of time in year *t*; t CO_2-e
CF_S	=	Carbon fraction of shrub biomass; t C (t.d.m.)$^{-1}$. A default value of 0.47 is used unless transparent and verifiable information can be provided to justify a different value.
R_S	=	Root-shoot ratio for shrubs; dimensionless. The default value of 0.40 is used unless transparent and verifiable information can be provided to justify a different value.
$A_{SHRUB,i}$	=	Area of shrub biomass estimation stratum *i*; ha
$b_{SHRUB,i}$	=	Shrub biomass per hectare in shrub biomass estimation stratum *i*; t d.m. ha^{-1}
BDR_{SF}	=	Ratio of shrub biomass per hectare in land having a shrub crown cover of 1.0 (i.e. 100 per cent) and the default above-ground biomass content per hectare in forest in the region/country where the NBS project activity is located; dimensionless. A default value of 0.10 should be used unless transparent and verifiable information can be provided to justify a different value.
b_{FOREST}	=	Default above-ground biomass content in forest in the region/country where the NBS project activity is located; t d.m. ha^{-1}. Values from Table 4.7 (p.4.22) of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* are used unless transparent and verifiable information can be provided to justify different values.
$CC_{SHRUB,i}$	=	Crown cover of shrubs in shrub biomass estimation stratum *i* at the time of estimation, expressed as a fraction (e.g. 10 per cent crown cover implies $CC_{SHRUB,i}$ = 0.10); dimensionless

15. Data and Parameters used in the tool

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

15.1. Data and Parameters not monitored

67. 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.

15.2. Data and Parameters monitored.

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

Data / Parameter 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):	GIS-system tools and/or ground-based measurements. Standard operating procedures (SOPs) prescribed under national forest or land inventory are applied. In the absence of these, SOPs from published handbooks, or from the IPCC GPG LULUCF 2003, are applied
Monitoring frequency:	At every verification
QA/QC procedures:	Quality control/quality assurance (QA/QC) procedures prescribed under national forest inventory are applied. In the absence of these, QA/QC procedures from published handbooks, or from the IPCC GPG LULUCF 2003, are applied

Data / Parameter Table 2: Shrub crown cover

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

Data / Parameter Table 3: Tree crown cover

Data / Parameter:	$CC_{TREE\_BSL,i}$
Data unit:	Dimensionless
Description:	Crown cover of trees in the baseline stratum *i*
Source of data:	Field measurement
Measurement procedures (if any):	Considering that the biomass in trees in the baseline is smaller compared to the biomass in trees in the project, a simplified method of measurement may be used for estimating tree crown cover. Ocular estimation of tree crown cover may be carried out or any other method such as the line transect method or the relascope method may be applied

Monitoring frequency:	Measured only once (at the beginning of the project)
QA/QC procedures:	Quality control/quality assurance (QA/QC) procedures prescribed under national forest inventory are applied. In the absence of these, QA/QC procedures from published handbooks, or from the IPCC GPG LULUCF 2003, are applied
Comment:	When land is subjected to periodic cycles (e.g. slash-and-burn, or clearing-regrowing cycles) so that the tree crown cover oscillates between a minimum and maximum values in the baseline, the value of this parameter should be set equal to half the maximum tree crown cover that would be achieved under the cycle

Appendix 1. Methods of plot biomass measurement

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

Table 1: Plot measurements and their conversion to tree biomass

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

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

Measurement of fixed area plots

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

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

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

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

$$b_{TREE,p,i} = \frac{B_{TREE,p,i}}{A_{PLOT,i}}$$

Equation (1)

Equation (2)

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

Equation (3)

$$B_{TREE,j,p,i} = \sum_{l} B_{TREE,l,j,p,i}$$

Where:

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

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

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

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

Where:

$B_{TREE,l,j,p,i}$	=	Biomass of tree *l* of species *j* in sample plot *p* of stratum *i*; t d.m.
$f_j(x_{1,l}, x_{2,l}, x_{3,l}, \ldots)$	=	Above-ground biomass of the tree returned by the allometric equation for species *j* relating the measurements of tree *l* to the above-ground biomass of the tree*;* t d.m. <u>Note.</u> The allometric equation used may be based on different units of inputs and outputs. For example, input values of diameter at breast height (dbh) may be in inches and output of biomass may be in pounds, rather than dbh in cm and biomass in kg or t d.m. In such a case, the function should be applied consistently (e.g. convert the dbh values from centimetre to inch units, obtain the tree biomass in pound, and then convert the biomass into metric tonne).
R_j	=	Root-shoot ratio for tree species *j*; dimensionless The value of R_j is estimated as $R_j = \frac{e^{(-1.085+0.9256\times\ln b)}}{b}$ where b is the above-ground tree biomass per hectare (in t d.m. ha^{-1}), unless transparent and verifiable information can be provided to justify a different value. <u>Note.</u> If trees have grown as coppice regeneration after a harvest, then the value of R_j should be multiplied by a factor equal to $v_{HARVEST}/v_{TREE}$ or 1, whichever is greater, where $v_{HARVEST}$ is the volume per hectare of trees harvested and v_{TREE} is the volume per hectare of trees standing in the plot at the time of measurement.

$V_{TREE,j}(x_{1,l}, x_{2,l}, x_{3,l}, \ldots)$ = Stem volume of tree *l* of species *j* in sample plot *p* of stratum *i*, estimated from the tree dimension(s) as entry data into a volume table or volume equation; m^3

Note. Where the volume table or volume equation predicts under-bark volume (i.e. wood volume, rather than gross stem volume), suitable correction should be applied to estimate the over-bark volume.

D_j = Density (over-bark) of tree species *j*; t d.m. m^{-3}

Values are taken from Table 4.13 (p.4.64) of 2006 IPCC Guidelines for National Greenhouse Gas Inventories unless transparent and verifiable information can be provided to justify different values.

Note. Where density (specific gravity) of the bark of a tree species is different from the density of the wood, suitable correction should be applied to estimate a conservative value of the overall (over-bark) density of tree stem.

$BEF_{2,j}$ = Biomass expansion factor for conversion of tree stem biomass to above-ground tree biomass, for tree species *j*; dimensionless

For ex-ante estimation, the value of $BEF_{2,j}$ is selected by applying, *mutatis mutandis*, the procedure described in paragraph 7 below.

For ex-post estimation the conservative default value of 1.15 is used, unless transparent and verifiable information can be provided to justify a different value.

6. For ex-ante estimation the allometric equation, volume table, or volume equation applied to a tree species is selected from the following sources (the most preferred source is 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.

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

Measurement of variable plots

8. 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 center of a sample plot using an angle-count instrument (e.g. a wedge prism or a relascope).

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

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

Where:

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

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

$$b_{TREE,j,p,i} = f_j(BA_{p,i}) * (1 + R_j)$$ *Equation (7)*

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

Where:

$b_{TREE,j,p,i}$	=	Tree biomass per hectare of species *j* in sample plot *p* of stratum *i*; t d.m. ha^{-1}
$f_j(BA_{p,i})$	=	Above-ground tree biomass per hectare in plot *p* returned by the allometric equation for species *j* relating the basal area of the plot to the above-ground tree biomass per hectare; t d.m. ha^{-1}
$v_{TREE,j}(BA_{p,i})$	=	Stem volume per hectare of trees of species *j* in sample plot *p* of stratum *i* estimated by using the basal area of the plot as entry data into a volume table or volume equation; m^3 ha^{-1}

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

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. 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.

Definition of the uncertainty discount factor

2. If uncertainty is not greater than 20% then discount factor equals 0 (zero). If uncertainty is equal or greater than 95% then discount factor equals 1 (one). Otherwise:

$$Discount\ factor = \frac{1 + sin\left[\frac{\pi}{3} * (4 * U - 2.3)\right]}{2} \quad \text{Equation (9)}$$

Where:

$sin\ (alpha)$	=	Function sinus. In this formula, $alpha$ is expressed in radians.
U	=	Uncertainty calculated according to instruction contained in para 9 (d) above; %

Graphical presentation of the discount factor is contained in **Figure 1** below.

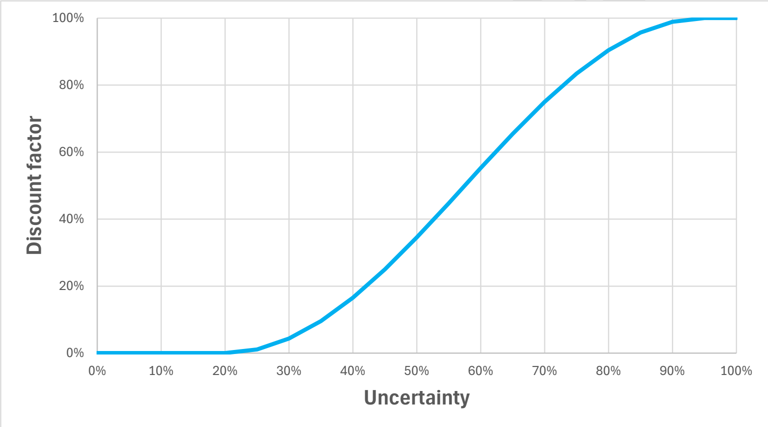

Figure 1. Discount factor vs. Uncertainty, as defined above.

Approximate numerical values of discount factor for selected values of uncertainty are presented in Table 1 below.

Uncertainty	Discount factor	Uncertainty	Discount factor
0% to 20%	0%	65%	65%
25%	1%	70%	75%
30%	4%	75%	83%
35%	10%	80%	90%
40%	17%	85%	96%
45%	25%	90%	99%
50%	35%	95%	100%
55%	45%	100%	100%
60%	55%	>100%	100%

Table 1. Look up data of discount factors for selected uncertainties.

Implementation of the discount factor

3. The implementation of the discount factor ensures that the estimate of GHG emission reduction and/or removal calculated at the project level is more likely to result in underestimation rather than overestimation of the climate impact of the project.

4. If the discount factor is applied separately to baseline and project calculations, then:

$$Discount_{baseline} = +\frac{1}{4} * CI * Discount\ factor$$

$$Discount_{project} = -\frac{1}{4} * CI * Discount\ factor$$

Equation (10)

Where:

CI = Confidence interval of the mean at confidence level defined in methodology implementing this tool.

5. If the discount factor is applied only one time to the final estimate of net GHG emission reduction/removal, then:

$$Discount_{final} = -\frac{1}{2} * CI * Discount\ factor$$

Equation (11)

6. The discounted conservative mean equals:

$$Conservative\ mean = Mean + \begin{cases} Discount_{baseline} \\ Discount_{project} \\ Discount_{final} \end{cases} (as\ appropriate)$$

Equation (12)

Appendix 3. Calculating correlation coefficient and slope of regression

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

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

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

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

DOCUMENT HISTORY

Version	Date	Comment
V 1.0	06/11/2024	Initial adoption by GCC Regulatory Committee based on the following: i. Consideration by individual Regulatory Committee members, followed by evaluation of the entire Regulatory Committee. ii. 30 days global stakeholder consultation taken place from 06/11/2024 to 05/12/2024.