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REDD Methodological Module

"Estimation of carbon stocks and changes in carbon stocks in the above-ground biomass carbon pool"

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I. SCOPE, APPLICABILITY AND PARAMETERS

Scope

This module allows for estimating carbon stocks and changes in carbon stocks in aboveground biomass. Calculation of emissions from aboveground biomass due to deforestation are dealt with in the baseline modules, referencing stocks calculated here.

Non-woody biomass (understory and herbaceous vegetation) is not treated in this methodology.

Applicability

This module is applicable to all forest types and age classes with stable or increasing stocks in the with-project case.

Output parameters

This methodology produces the following parameters:

Parameter	SI Unit	Description
$C_{AB\_tree,\,i,\,t=0}$	t CO_2-e ha^{-1}	Initial carbon stock in aboveground biomass in strata *i*
$\Delta C_{AB\_tree,\,i,\,t}$	t CO_2-e ha^{-1}	Carbon stock changes in aboveground biomass in strata *i* at time *t*

II. PROCEDURES

Estimation of initial carbon stocks in aboveground tree biomass ($C_{AB\_tree\ i,t=0}$)

The mean carbon stock in aboveground biomass per unit area is estimated based on field measurements in sample plots. For estimation of initial stocks at t=0 it is acceptable to use pre-

CLIMATEFOCUS Silvestrum WINROCK INTERNATIONAL Putting Ideas to Work CARBON·DECISIONS international TerraCarbon LLC existing forest inventory data, providing the necessary parameters, that is not more than 5 years old.

Two methods are available: the Biomass Conversion and Expansion Factors (*BCEF*) method, and the Allometric Equations method. If aboveground biomass increment is monitored in the project, plots must be permanent.

BCEF method

Step 1: Determine based on available data, e.g. volume tables (*ex ante*) and measurements (*ex post*), the diameter (*DBH*, at typically 1.3 m [4.3 ft] aboveground level), and also preferably merchantable height (*MH*), of all the trees above some minimum *DBH* in the sample plots.

Step 2: Estimate the volume of the commercial (merchantable) component of trees based on available equations or yield tables (if locally derived equations or yield tables are not available use relevant regional, national or default data as appropriate and validated (see parameters)). It is possible to combine steps 1 and 2 if there are field instruments (e.g. a relascope) that measure the volume of each tree more directly.

Step 3: Choose *BCEF*. If relevant information is available the *BCEF* should be adjusted for forest type or stand structure.

Step 4: Convert the volume of the commercial component of the trees into the plot level carbon stock biomass of the commercial component of trees via wood density and carbon fraction. Volumes are summed to the plot level before applying the BCEF.

$$C_{AB\_tree,sp,i,t=0} = \sum_{j=1}^{S} \left(BCEF_j * CF_j \sum_{l=1}^{N_{j,sp,i,t=0}} V_{l,j,sp,i,t=0} \right) \qquad (1)$$

Where:

$C_{AB\_tree,sp,i\ t=0}$	Aboveground biomass carbon stock of trees in plot *sp*, in stratum *i* at time *t=0*; t C
$V_{l,j,sp,i,t=0}$	Merchantable volume of tree *l* of species *j* in plot *sp* in stratum *i* at time *t=0*, m^3
BCEFj	Biomass conversion and expansion factor for conversion of merchantable volume to total aboveground tree biomass for tree species *j*; dimensionless
CFj	Carbon fraction of biomass for tree species *j*; t C t^{-1} d.m.
l	*1, 2, 3, …* $N_{j,sp,i,t}$ sequence number of individual trees of species *j* in sample plot *sp* in stratum *i* at time *t*
i	*1, 2, 3, …M* strata
j	*1, 2, 3 … S* tree species

t=0	*0* years elapsed since start of the project activity

Step 5: Calculate the mean aboveground biomass carbon stock for each stratum, converted to carbon dioxide equivalents:

$$C_{AB\_tree,i,t=0} = \frac{1}{Asp_i} * \sum_{sp=1}^{P_i} C_{AB\_tree\_sp,i,t=0} * \frac{44}{12} \qquad (2)$$

Where:

$C_{AB\_tree,i,t=0}$	Mean aboveground biomass carbon stock in stratum *i* at time *t=0*; t CO_2-e ha^{-1}
$C_{AB\_tree\_sp,i\ t=0}$	Mean aboveground biomass carbon stock of trees in plot *sp*, in stratum *i* at time *t=0*; t C
Asp_i	Total area of all sample plots in stratum *i*; ha
sp	*1, 2, 3 … P_i* sample plots in stratum *i*
i	*1, 2, 3 … M* strata
t=0	*0* years elapsed since the start of the project activity
44/12	Ratio of molecular weight of CO_2 to carbon, t CO_2-e t C^{-1}

Allometric Equation method

Step 1: As with Step 1 of the *BCEF* method.

Step 2: Select or develop an appropriate and validated allometric equation (if possible species-specific, or if not from a similar species).

Step 3: Estimate carbon stock in aboveground biomass for each individual tree *l* of species *j* in the sample plot located in stratum *i* using the selected or developed allometric equation applied to the tree dimensions resulting from Step 1 (if using height, use total height (*H*) in place of merchantable height (*MH*)), and sum the carbon stocks in the sample plot:

$$C_{AB\_tree,j,sp,i,t=0} = \sum_{l=1}^{N_{j,sp,i,t}=0} f_j(DBH, H) * CF_j \qquad (3)$$

Where:

$C_{AB\_tree,j,sp,i,t=0}$	Carbon stock in aboveground biomass of trees of species *j* in plot *sp* in stratum *i* at time *t=0*; t C
CFj	Carbon fraction of biomass for tree species *j*; t C t^{-1} d.m.

$f_j(DBH,H)$	Allometric equation for species *j* linking diameter at breast height (*DBH*) and possibly total height (*H*) to aboveground biomass of trees; t. d.m. tree^{-1}
i	*1, 2, 3, …M* strata
j	*1, 2, 3 … S* tree species
l	*1, 2, 3, … $N_{j,sp,i,t}$* sequence number of individual trees of species *j* in sample plot *sp* in stratum *i* at time *t*
t=0	*0* years elapsed since start of the project activity

Step 4: Calculate total carbon stock in the aboveground biomass of all trees present in sample plot *sp* in stratum *i* at time *t*

$$C_{AB\_tree,sp,i,t=0} = \sum_{j=1}^{S} C_{AB\_tree,j,sp,i,t=0} \qquad (4)$$

Where:

$C_{AB\_tree,sp,i,t=0}$	Aboveground biomass carbon stock of trees in sample plot *sp* of stratum *i* at time *t=0*, t C
$C_{AB\_tree,,j,sp,i,t=0}$	Carbon stock in aboveground biomass of trees of species *j* in sample plot *sp* in stratum *i* at time *t=0*; t C
i	*1, 2, 3, …M* strata
j	*1, 2, 3 … S* tree species
t=0	*0* years elapsed since the start of the project activity

Step 5: Calculate the mean carbon stock in aboveground biomass for each stratum, converted to carbon dioxide equivalents:

$$C_{AB\_tree,i,t=0} = \frac{1}{Asp_i} * \sum_{sp=1}^{P_i} C_{AB\_tree,sp,i,t=0} * \frac{44}{12} \qquad (5)$$

Where:

$C_{AB\_tree,i,t=0}$	Mean aboveground biomass carbon stock in stratum *i* at time *t=0*; t CO_2-e ha^{-1}
$C_{AB\_tree,sp,i,t=0}$	Aboveground biomass carbon stock of trees in sample plot *sp* of stratum *i* at time *t=0*, t C
Asp_i	Total area of all sample plots in stratum *i*; ha
sp	*1, 2, 3 … Pi* sample plots in stratum *i*

i	*1, 2, 3 … M* strata
t=0	*0* years elapsed since the start of the project activity
44/12	Ratio of molecular weight of CO_2 to carbon, t CO_2-e t C^{-1}

Baseline

This module does not track growth in aboveground biomass occurring prior to deforestation in areas deforested the baseline scenario. Stocks of aboveground biomass in areas deforested in the baseline are assumed to be constant, or are matched and canceled by (the same) growth measured in the with-project case if the election is made to monitor growth in the with-project case (see below).

For areas not deforested in the baseline scenario, growth is not tracked (and stocks are conservatively assumed to be constant) in both baseline and with-project scenarios.

Post-deforestation stocks are equally treated as constant and this value may be the ultimate stocks of the designated replacement land use. Where the land use is part of a cycle, the time-weighted average of the carbon stocks can be used. Proxy measurement sites must represent the land use, site conditions and management practices identified as the most likely conversion use in the baseline, and documentation must be provided to the satisfaction of the verifier establishing that the lands are representative.

Actual carbon stock change in aboveground biomass in the with-project scenario

Two alternatives are provided for accounting forest growth in the with-project case, either:

1. conservatively assume no growth in aboveground biomass in areas deforested in the baseline, and thus no monitoring required following initial quantification of stocks at *t*=0, or
2. directly monitor aboveground biomass in the project for baseline deforested areas using permanent sample plots.

Carbon stock changes in aboveground biomass are estimated using the gain-loss method, where directly measured incremental growth minus tree mortality and timber extraction is treated as net change in carbon stocks.

$$\Delta C_{AB\_tree i,t} = \Delta C_{G,AB\_tree i,t} - \Delta C_{L,AB\_tree i,t} \quad (6)$$

Where:

$\Delta C_{AB\_tree\ i,t}$ Annual net carbon stock change in aboveground biomass for stratum *i*, at time *t*; t CO_2-e ha^{-1} yr^{-1}

$\Delta C_{G,AB\_tree\ i,t}$	Annual increase in aboveground biomass carbon stock due to biomass growth (diameter and or height increment) for stratum *i,* at time *t*; t CO_2-e ha^{-1} yr^{-1}
$\Delta C_{L,AB\_tree\ i,t}$	Annual decrease in aboveground biomass carbon stock due to tree mortality or timber extraction for stratum *i,* at time *t*; t CO_2-e ha^{-1} yr^{-1}
i	*1, 2, 3 … M* strata
t	*1, 2, 3 … t* years elapsed since the start of the project activity

The annual decrease in aboveground biomass carbon stock for stratum *i* at time *t* ($\Delta C_{L,AB\_tree\ i,t}$) is estimated in the same way as aboveground biomass carbon stocks (Equations 1-5, but instead expressed as t CO_2-e ha^{-1} yr^{-1}), restricting per tree biomass estimates to trees present at time *t-1* but absent or visibly dead at time *t*. Treatment of mortality and removal as losses from aboveground biomass reconciles with the stock change based accounting of dead wood and wood products pools.

The annual increase in aboveground biomass carbon stock due to biomass growth for stratum *i* at time *t* ($\Delta C_{G,AB\_tree\ i,t}$) are estimated through the following steps using either the Allometric Equations method or, where allometric equations are not available, restricting estimation of aboveground biomass increment to the commercial stem component[1]. Trees used in the estimation are restricted to trees present at both time *t* and time *t-1*, and trees present at time *t* but absent (i.e. below minimum diameter threshold) at time *t-1* (incremental growth of recruiting stems), in which case diameter at time *t-1* is set as the minimum diameter measured in the sample plots.

Step 1: Estimate annual increase in aboveground biomass carbon stock of trees in sample plot *sp* in stratum *i* at time *t.*

For Allometric method

$$\Delta C_{G\_AB\_tree,sp,i,t} = \sum_{j=1}^{S} \sum_{l=1}^{N_{j,sp,i,t}} \left(f_j(DBH_t, H_t) * CF_j\right) - \left(f_j(DBH_{t-1}, H_{t-1}) * CF_j\right) \quad (7)$$

where:

$\Delta C_{G,AB\_tree,sp,i,t}$	Annual increase in aboveground biomass carbon stock of trees in sample plot *sp* in stratum *i* at time *t*; t C yr^{-1}
CFj	Carbon fraction of biomass for tree species *j*; t C t^{-1} d.m.
$f_j(DBH,H)$	Allometric equation for species *j* linking diameter at breast height (*DBH*) and possibly total height (*H*) to aboveground biomass of trees; t. d.m.

1 Note that BCEFs are not applied on a per stem basis, hence cannot be used to calculate aboveground biomass *increment* per stem

	tree^{-1}; DBH_{t-1} of trees absent at time *t-1* is equal to the minimum DBH measured in the sample plots
i	*1, 2, 3, …M* strata
j	*1, 2, 3 … S* tree species
l	*1, 2, 3, …* $N_{j,i,sp,t}$ sequence number of individual trees of species *j* in sample plot *sp* in stratum *i* at time *t*; restricted to trees present at both time *t* and time *t-1*, and trees present at time *t* but absent at time *t-1*
t	*1, 2, 3 … t* years elapsed since start of the project activity

For commercial stem component only

$$\Delta C_{G\_AB\_tree,sp,i,t} = \sum_{j=1}^{S} \sum_{l=1}^{N_{j,sp,i,t}} (V_{l,j,sp,i,t} * D_j * CF_j) - (V_{l,j,sp,i,t-1} * D_j * CF_j) \quad (8)$$

Where:

$\Delta C_{G\_AB\_tree,sp,i\,t}$	Annual increase in aboveground biomass carbon stock of trees in sample plot *sp* in stratum *i* at time *t*; t C yr^{-1}
$V_{l,j,sp,i,t}$	Merchantable volume of tree *l* of species *j* in sample plot *sp* in stratum *i* at time *t,* m^3; $V_{l,j,sp,i,t-1}$ of trees absent at time *t-1* is equal to the volume corresponding to the minimum DBH measured in the sample plots
D_j	Basic wood density of species *j*; t d.m.m^{-3}
CF_j	Carbon fraction of biomass for tree species *j*; t C t^{-1} d.m.
l	*1, 2, 3, …* $N_{j,i,sp,t}$ sequence number of individual trees of species *j* in sample plot *sp* in stratum *i* at time *t*; restricted to trees present at both time *t* and time *t-1*, and trees present at time *t* but absent at time *t-1*
i	*1, 2, 3, …M* strata
j	*1, 2, 3 … S* tree species
t	*1, 2, 3 … t* years elapsed since start of the project activity

Step 2: Calculate the mean annual increase in aboveground biomass carbon stock of trees for each stratum, converted to carbon dioxide equivalent:

$$\Delta C_{G\_AB\_tree,i,t} = \frac{1}{Asp_i} * \sum_{sp=1}^{P_i} \Delta C_{G\_AB\_tree,sp,i,t} * \frac{44}{12} \quad (9)$$

Where:

$\Delta C_{G\_AB\_tree,i,t}$	Mean annual increase in aboveground biomass carbon stock of trees in stratum *i* at time *t*; t CO_2-e ha^{-1} yr^{-1}
$\Delta C_{G,AB\_tree,sp,i,t}$	Annual increase in aboveground biomass carbon stock of trees in plot *sp* in stratum *i* at time *t*; t C yr^{-1}
Asp_i	Total area of all sample plots in stratum *i*; ha
sp	*1, 2, 3 … Pi* sample plots in stratum *i*
i	*1, 2, 3 … M* strata
t	*1, 2, 3 … t* years elapsed since the start of the project activity
44/12	Ratio of molecular weight of CO_2 to carbon, t CO_2-e t C^{-1}

III. DATA AND PARAMETERS NOT MONITORED (DEFAULT OR POSSIBLY MEASURED ONE TIME)

Data / parameter:	*CF*
Data unit:	t C t^{-1} d.m.
Used in equations:	1, 3, 7, 8
Description:	Carbon fraction of dry matter
Source of data:	Default value 0.47 t C t^{-1} d.m. can be used, or species specific values from the literature (e.g. IPCC 2006 INV GLs AFOLU Chapter 4 Table 4.3).
Measurement procedures (if any):	
Any comment:	

Data / parameter:	*BCEF*
Data unit:	Dimensionless
Used in equations:	1
Description:	Biomass conversion and expansion factor for conversion of commercial wood volume to total aboveground tree biomass
Source of data:	The source of data shall be chosen with priority from higher to lower preference as follows: (a) Existing local forest type-specific; (b) National forest type-specific or eco-region-specific (e.g. from national GHG inventory); (c) Forest type-specific or eco-region-specific from neighboring countries with similar conditions. Sometimes (c) might be preferable to (b); (d) Global forest type or eco-region-specific (e.g. IPCC 2006 INV GLs AFOLU Chapter 4 Table 4.5)
Measurement procedures (if any):	
Any comment:	Alternatively, BCEF, where not directly available, can be calculated as wood density (t dry mass m^{-3} green volume) * BEF (Biomass Expansion Factor = ratio of aboveground biomass to biomass of the commercial volume). Species-specific BCEFs may not always be available, and may be difficult to apply with certainty in the typically species rich forests of the humid

	tropics, hence it is acceptable practice to use BCEFs developed for regions or groups of species, provided that their accuracy has been validated with direct site-specific data (per guidance below). It is necessary to verify the applicability of BCEFs used. BCEFs are verified by both: 1. Review of source data from which BCEF was derived and confirmation that the source data is representative of the forest type and conditions in the project and covers the range of potential commercial volumes. and by assessing accuracy of BCEF on a per tree basis by: 2. Limited Destructive Sampling ▪ Select at least 5 trees covering the range of DBH existing in the project area ▪ Measure DBH and commercial height and calculate volume using the same procedures/equations used to generate commercial volumes to which BCEFs will be applied ▪ Fell and weigh the aboveground biomass to determine the total (wet) weight of the stem and branch components; ▪ Extract and immediately weigh subsamples from each of the wet stem and branch components, followed by oven drying at 70oC to determine dry biomass; ▪ Determine the total aboveground biomass (t) of each tree from the wet weights and the averaged ratios of wet and dry weights of the stem and branch components If the total aboveground biomass of the harvested trees is within ±10% of the total aboveground biomass predicted by the selected default BCEF (applied to the calculated commercial volume), and is not biased, then values from the BCEF may be used. Otherwise, the BCEF must be re-parameterized to conform to the validation data before using, or another BCEF selected.

Data / parameter:	*D*
Data unit:	t d.m. m^{-3}
Used in equations:	8
Description:	Basic wood density
Source of data:	The source of data shall be chosen with priority from higher to lower

	preference as follows: (a) National species-specific or group of species-specific (e.g. from National GHG inventory); (b) Species-specific or group of species-specific from neighboring countries with similar conditions. Sometimes (b) may be preferable to (a); (c) Global species-specific or group of species-specific (e.g. IPCC 2006 INV GLs AFOLU Chapter 4 Tables 4.13 and 4.14). Species-specific wood densities may not always be available, and may be difficult to apply with certainty in the typically species rich forests of the humid tropics, hence it is acceptable practice to use wood densities developed for forest types or species groups.
Measurement procedures (if any):	N/A
Any comment:	Wood densities must be validated with either limited destructive sampling or direct measurement of wood hardness (e.g. with a Pilodyn wood tester) in the field and correlating with wood density. Samples or measurements should be from 20-30 trees. For validation of mean forest type or species group wood densities, representation of species in the sample should be proportional to their occurrence in terms of basal area or volume in the project area (not abundance or stem density). Samples should provide representation across the length of the tree. Wood samples are cut in discs and thickness and diameter measured to calculate green volume. Samples are oven dried (70o C) to a constant weight in the laboratory, and density calculated as dry weight (g) per unit green volume (cm3). If the density of the samples/measurements (or mean density in the case of forest type or species group means) is within ±10% of the selected density values, then the selected density values may be used. Otherwise, a new density value must be developed with more extensive sampling, using the validation samples as a base.

Data / parameter:	$f_j(DBH,H)$
Data unit:	t d.m. tree^{-3}
Used in equations:	3, 7
Description:	Allometric equation for species j linking diameter at breast height (DBH) and possibly total height (H) to aboveground biomass of living trees

Source of data:	Whenever available, use allometric equations that are species-specific or group of species-specific, provided the equations have been derived using a wide range of diameters and heights, based on datasets that comprise at least 20 trees. Otherwise, default equations from IPCC literature, national inventory reports or published peer-reviewed studies may be used – such as those provided Tables 4.A.1 to 4.A.3 of the GPG-LULUCF (IPCC 2003) or in Pearson, T., Walker, S. and Brown, S. 2005. Sourcebook for Land Use, Land-Use Change and Forestry Projects. Winrock International and the World Bank Biocarbon Fund. 57pp. Available at: http://www.winrock.org/Ecosystems/files/Winrock-BioCarbon_Fund_Sourcebook-compressed.pdf Species-specific allometric equations may not always be available, and may be difficult to apply with certainty in the typically species rich forests of the humid tropics, hence it is acceptable practice to use equations developed for regions or groups of species, provided that their accuracy has been validated with direct site-specific data (per guidance below).
Measurement procedures (if any):	
Any comment:	It is necessary to verify the applicability of equations used. Allometric equations can be verified either by: 1. Review of source data from which equation was derived and confirmation that the source data is representative of the forest type/species and conditions in the project and covers the range of potential DBH. and either (2a or 2b) 2a. Destructive Sampling ▪ Selecting at least 5 trees covering the range of DBH existing in the project area (but excluding trees less than 15 years old for which there is rarely a great relative inaccuracy in equations), and felling and weighting the aboveground biomass to determine the total (wet) weight of the stem and branch components; ▪ Extracting and immediately weighing subsamples from each of the wet stem and branch components, followed by oven drying at 70oC to determine dry biomass; ▪ Determining the total dry weight of each tree from the wet weights and the averaged ratios of wet and dry weights of the stem and branch components. 2b. Limited Measurements ▪ Select at least 10 trees per species distributed across the age range (but excluding trees less than 15 years old for which there is rarely a great relative

	inaccuracy in equations) ▪ Calculate volume of tree from basal and top diameters and tree height. Multiply by species-specific density to gain biomass of bole. Add an additional 20% to approximately cover biomass of branches If the biomass of the harvested trees is within ±10% of the mean values predicted by the selected default allometric equation, and is not biased, then mean values from the equation may be used. Otherwise, the equation must be re-parameterized to conform to the validation data before using, or another equation selected.

IV. DATA AND PARAMETERS MONITORED

Data / parameter:	*V*
Data unit:	m^3
Used in equations:	1, 8
Description:	Merchantable volume of tree
Source of data:	Calculated from volume tables or equations linking diameter (*DBH*, at typically 1.3 m aboveground level), and also preferably merchantable height (*MH*), to commercial (merchantable) volume of trees above some minimum *DBH* in the sample plots. If locally derived equations or yield tables are not available use relevant regional, national or default data as appropriate and validated (as per validation procedures for allometric equations).
Measurement procedures (if any):	Commercial volume can be alternatively measured directly using appropriate field instruments (e.g. a relascope).
Any comment:	

Data / parameter:	*Asp*
Data unit:	ha
Used in equations:	2, 5, 9
Description:	Total area of all sample plots
Source of data:	Recording and archiving of number and size of sample plots
Measurement procedures (if any):	
Monitoring	

frequency:	
QA/QC procedures:	
Any comment:	

Data / parameter:	*DBH*
Data unit:	cm
Used in equations:	3, 7
Description:	Diameter at breast height of tree
Source of data:	Field measurements in sample plots
Measurement procedures (if any):	Typically measured 1.3m aboveground. Measure all trees above some minimum *DBH* in the sample plots. The minimum *DBH* varies depending on tree species and climate; for instance, the minimum *DBH* may be as small as 2.5 cm or as high as 20 cm.
Monitoring frequency:	
QA/QC procedures:	
Any comment:	

Data / parameter:	*H*
Data unit:	m
Used in equations:	3, 7
Description:	Total height of tree
Source of data:	Field measurements in sample plots
Measurement procedures (if any):	
Monitoring frequency:	
QA/QC procedures:	
Any comment:	