# METHODOLOGY FOR AFFORESTATION, REFORESTATION AND REVEGETATION PROJECTS

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# Relationship to Approved or Pending Methodologies

Approved and pending methodologies under the VCS Program and approved GHG programs, that fall under the same sectoral scope (14) and agriculture, forestry and other land use (AFOLU) project category of afforestation, reforestation, and revegetation (ARR), were reviewed to determine whether an existing methodology could reasonably be revised to meet the objective of this proposed methodology. One methodology was identified, as set out in Table 1.

**Table 1: Similar Methodologies**

| Methodology | Title | GHG Program | Comments |
|---|---|---|---|
| AR-ACM0003 | *A/R Large-scale Consolidated Methodology – Afforestation and reforestation of lands except wetlands* | CDM | The VCS does not currently have its own ARR methodology. The ACM0003 has procedures for the quantification of carbon pools that are used in the new methodology. It has procedures for the determination of the baseline scenario and additionality that are upgraded in the new methodology. |
| AR-AMS0007 | *A/R Small-scale Methodology – Afforestation and reforestation project activities implemented on lands other than wetlands* | CDM | The VCS does not currently have its own ARR methodology, and seeks to provide a unified accounting approach for ARR projects. The new methodology does not distinguish between large- and small-scale activities. |
| AR-AM0014 | *A/R Large-scale Methodology – Afforestation and reforestation of degraded mangrove habitats* | CDM | Restoration of mangroves is treated in VM0033. |
| AR-AMS0003 | *A/R Small-scale Methodology – Afforestation and reforestation project activities implemented on wetlands* | CDM | Afforestation and reforestation project activities implemented on wetlands are treated in VM0033. |

# CONTENTS

# 1 SOURCES

This methodology is based on the following methodologies:

- Clean Development Mechanism (2013). *AR-ACM0003: A/R Large-scale Consolidated Methodology – Afforestation and reforestation of lands except wetlands, v.02.0*
- Clean Development Mechanism (2007). *Tool for testing significance of GHG emissions in A/R CDM project activities, v.01*
- Clean Development Mechanism (2011). *AR-TOOL16: A/R Methodological Tool – Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities*, *v.01.1.0*

This methodology uses the latest version of the following tools:

- *VT0001 Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities*

# 2 SUMMARY DESCRIPTION OF THE METHODOLOGY

| Additionality and Crediting Method | |
|---|---|
| Additionality | Performance Method or Project Method |
| Crediting Baseline | Performance Method or Project Method |

This methodology was developed from the Clean Development Mechanism *AR-ACM0003: A/R Large-scale Consolidated Methodology – Afforestation and reforestation of lands except wetlands* and associated tools. The original CDM methodology has been substantially revised to incorporate innovative approaches to standardize additionality and crediting baselines, account for leakage, and accommodate small-scale tree planting activities.

This methodology is applicable to all afforestation, reforestation, and revegetation activities that do not take place on organic soils or wetlands and result in an intentional manipulation of the water table, or that do not take place in tidal wetlands. Two quantification approaches are provided: an area-based quantification approach, and a census-based quantification approach.

The area-based approach:

- Uses traditional plot-based sampling methods, scaling biomass per unit area estimates to the project level using project area as the multiplier, that is, the principal project boundary is defined by the project geographic area; and
- Uses a performance benchmark to demonstrate additionality and set the crediting baseline. The performance benchmark is calculated from ex-ante observations of business-as-usual transitions from non-forest to forest cover in areas comparable to the project area. Provisions are also made available for a simplified “zero” performance benchmark where initial conditions clearly preclude the establishment of vegetative cover.

The census-based approach:

- Is applicable where the project activity does not result in a change in land use and where a complete census of plantings is practical (e.g., urban forestry, agroforestry, forest shelterbelts, plantings directed to rural homesteads, revegetation that does not meet the forest definition);
- Scales biomass per tree to the project level using a complete census of planted trees, that is, the principal project boundary is defined by the tree itself; and
- Uses project methods — demonstration of implementation barriers — to demonstrate additionality and identify the baseline scenario.

Pools and sources accounted for in the project boundary include woody (tree and shrub) above and belowground biomass, herbaceous biomass, dead wood, harvested wood products, litter, soil organic carbon, non-$CO_2$ emissions from biomass burning, and $N_2O$ emissions from nitrogen fertilizer. Detailed guidance is provided on calculating maximum long-term average GHG benefit where project activities include even-aged harvesting.

The methodology references the *Module for Estimating Leakage from ARR Activities*, which provides a standardized approach to estimating the emissions from leakage based on project-specific conditions. The tool accounts for leakage related to the displacement of pre-project agricultural activities whether it is caused by the baseline agent (activity-shifting leakage) or by other actors (market leakage).

# 3 DEFINITIONS

In addition to the definitions set out in the *VCS Program Definitions*, the following definitions apply to this methodology:

**Planting unit**

Clearly defined individual woody plants (e.g., tree, shrub, bamboo clump) that are identifiable in the field and subject to a complete census. Used in the census-based quantification approach (Section 8.2)

**Vegetative propagation**

Deliberate artificial establishment of new planting units from vegetative material (e.g., cuttings or buds) sourced directly from parent planting units included in the project boundary. Relevant when using the census-based quantification approach (Section 8.2)

# 4 APPLICABILITY CONDITIONS

This methodology is applicable under the following conditions:

- The project activity qualifies as afforestation, reforestation, or revegetation. This may include direct (e.g., manual planting, broadcast seeding) and indirect activities (e.g., activities that permit or facilitate natural regeneration, such as herbivory exclosures).

This methodology is not applicable under the following conditions:

- Project activities take place on organic soils or wetlands and result in an intentional manipulation of the water table (i.e., the project activity must not involve manipulation of hydrology or otherwise affect hydrology). If species planted are other than those likely to have occurred under historic natural conditions in the project area, per best available knowledge (relevant literature and/or consultation with local experts), it is assumed that the project activity on organic soils or wetlands results in an intentional manipulation of the water table.
- Project activities take place in tidal wetlands (e.g., mangroves, salt marshes).

The methodology allows for two quantification approaches: area-based and census-based. The area-based approach scales estimates of biomass per hectare to the project level using an area multiplier. The census-based approach scales estimates of biomass per planting to the project level using a census, and can be appropriate where a full census of plantings is practical.

One or the other approach may be used, provided approach-specific applicability conditions are met. One approach must be selected at the project start date and used for the entire project crediting period.

Quantification approaches and their applicability conditions are outlined in Table 2.

**Table 2: Quantification Approaches and Applicability Conditions**

| Quantification Approach | Applicability Conditions | Project Accounting Boundary | Crediting Baseline | Additionality |
|---|---|---|---|---|
| **Area-based:** Uses project area, $A_t$, as the scaling parameter. Applies plot-based sampling | The ARR activity can be clearly delineated spatially, and area calculated using GIS. | See Tables 3 and 4 | Performance benchmark | Performance benchmark |
| **Census-based:** Uses a complete census of individual planting units (e.g., tree, shrub, bamboo clump), $N_i$, as the scaling parameter. In essence, the accounting boundary is the planted tree itself. This approach is best suited to dispersed planting activities (e.g., urban forestry, agroforestry around homesteads, shelterbelts, revegetation that does not meet the forest definition) that do not result in a change in land cover or land use, and where it is practical to maintain a complete census of all plantings. The approach offers advantages over more traditional plot-based sampling (e.g., delineation of sample plot boundaries is not required, no corrections for slope or boundary overlap, no area estimation). | Individual planting units of woody biomass are clearly defined (e.g., tree, shrub, bamboo clump) and identifiable in the field, with each planting unit given a unique ID and location recorded with GPS.<br><br>The project activity does not result in a change in land use.<br><br>A complete census of all planting units is maintained.<br><br>No pre-existing woody biomass (e.g., trees or shrubs) is removed to provide space for the plantings. | Limited to:<br>• Above- and belowground woody biomass<br>• Dead wood<br>• Harvested wood products<br>• Emissions from biomass burning<br>• Emissions from any nitrogen fertilizer application<br><br>No spatial boundary | Project method where baseline scenario = absence of planting units | Project method |

# 5 PROJECT BOUNDARY

The spatial extent of the project boundary encompasses all lands subject to implementation of the ARR project activity. Requirements on delineation of the project boundary and estimation of the project area are provided in Section 9.1 for parameter $A_t$, area in year $t$. Note that the project boundary must be delineated even for the census-based quantification approach, in order to assess VCS eligibility and compliance with applicability conditions of the methodology.

Selected carbon pools included in the project boundary in the baseline and project scenarios are listed in Table 3 below.

Carbon pools may be deemed *de minimis* and do not need to be accounted for if the total omitted decrease in carbon stocks or increase in GHG emissions amounts to less than 5% of the total GHG benefit generated by the project, applying procedures outlined in Appendix 2.

**Table 3: Selected Carbon Pools in the Project Boundary**

| Carbon Pool | Included? | Justification/Explanation |
|---|---|---|
| Aboveground woody biomass (trees and shrubs) | Yes | Major carbon pool that may significantly increase or decrease in both the baseline and project scenarios, in the case of establishment or presence of tree or shrub vegetation |
| Aboveground non-woody biomass | Yes | Optional in afforestation and reforestation project activities<br>Must be included where the project activity may significantly reduce the pool |
| Belowground woody biomass (trees and shrubs) | Yes | Major carbon pool that may significantly increase or decrease in both the baseline and project scenarios, in the case of establishment or presence of tree or shrub vegetation |
| Belowground non-woody biomass | Yes | Optional in afforestation and reforestation project activities<br>Must be included where the project activity may significantly reduce the pool |
| Dead wood | Optional | Carbon stock in this pool may increase due to implementation of the project activity.<br>Must be included where the project activity may significantly reduce the pool |
| Litter | Optional | Must be included where the project activity may significantly reduce the pool<br>Excluded if using the census-based quantification approach |

| | | |
|---|---|---|
| Soil organic carbon (SOC) | Optional | Carbon stock in this pool may increase due to implementation of the project activity.<br>Must be included where the project activity may significantly reduce the pool<br>Excluded if using the census-based quantification approach |
| Harvested wood products | Optional | Carbon stock in this pool may increase due to implementation of the project activity.<br>Conservative to exclude |

The greenhouse gases included in or excluded from the project boundary are shown in Table 4.

**Table 4: GHG Sources Included In or Excluded From the Project Boundary**

| Source | | Gas | Included? | Justification/Explanation |
|---|---|---|---|---|
| Baseline | Burning of tree biomass (emissions from burning non-tree biomass not included; *de minimis*) | $CO_2$ | No | Conservatively omitted |
| | | $CH_4$ | No | Conservatively omitted |
| | | $N_2O$ | No | Conservatively omitted |
| | Emissions from nitrogen fertilizer | $CO_2$ | No | Conservatively omitted |
| | | $CH_4$ | No | Conservatively omitted |
| | | $N_2O$ | No | Conservatively omitted |
| | Burning of fossil fuels | $CO_2$ | No | *De minimis* |
| | | $CH_4$ | No | *De minimis* |
| | | $N_2O$ | No | *De minimis* |
| Project | Burning of tree biomass (emissions from burning non-tree biomass not included; *de minimis*) | $CO_2$ | Yes | Burning of biomass for the purpose of site preparation, or as part of forest management, is allowed under this methodology. Decreases in carbon stock due to burning are accounted for as a carbon stock change. |

| | | | | |
|---|---|---|---|---|
| | | $CH_4$ | Yes | Burning of biomass for the purpose of site preparation, or as part of forest management, is allowed under this methodology. |
| | | $N_2O$ | Yes | Burning of biomass for the purpose of site preparation, or as part of forest management, is allowed under this methodology. |
| | Emissions from nitrogen fertilizer | $N_2O$ | Conditional on project activity | $N_2O$ emissions from nitrogen-containing soil amendments are included in the scenario where nitrogen fertilizer is applied as part of the project activity. $N_2O$ emissions are conservatively set to zero in the baseline. |
| | Burning of fossil fuels | $CO_2$ | | *De minimis* |
| | | $CH_4$ | | *De minimis* |
| | | $N_2O$ | | *De minimis* |

# 6 BASELINE SCENARIO

## Area-based quantification

A performance benchmark is used to set the crediting baseline. The performance benchmark, defined as the business-as-usual rate of establishment of new vegetative cover and productivity relative to the project, is set based on observations from a network of representative sample plots outside of the project area. Procedures to define the performance benchmark are provided in Appendix 1.

## Census-based quantification

If using the census-based quantification approach, the crediting baseline employs a project method, where the baseline scenario is represented by the absence of planting, i.e., planting units are not propagated and planted due to an implementation barrier demonstrated via procedures in Step 2b of Section 7.

# 7 ADDITIONALITY

This methodology uses a performance method or a project method for the demonstration of additionality.

## Step 1: Regulatory Surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the *VCS Methodology Requirements*.

If the project is using the area-based quantification approach, additionality is demonstrated via application of the performance benchmark (Step 2a). If the project is using the census-based quantification approach, additionality is demonstrated using a project method (Step 2b).

## Step 2a: Performance Benchmark

Requirements for deriving the performance benchmark are detailed in Appendix 1, and application of the performance benchmark is found in Section 8.5, Equation (39).

## Step 2b: Project Method

It must be demonstrated that one or more barriers prevent the implementation of the ARR project activity, using the following steps:

1) Establish that there are barriers that would prevent implementation of the type of proposed project activity if the project activity was not registered as a VCS AFOLU project. The barriers should not be specific to the project or project proponent(s). Such barriers may include, among others:

    a) Investment barriers such as:

        i) The VCS AFOLU project generates discounted financial or economic benefits other than VCS-related income, in the first 20 years, that total less than 5% of discounted implementation costs

        ii) Similar activities have only been implemented with grants or other non-commercial finance terms (e.g., government subsidies or philanthropic funding). In this context, similar activities are defined as activities of a similar scale that take place in a comparable environment with respect to regulatory framework and are undertaken in the relevant geographical area

    b) Institutional barriers such as: risk related to changes in government policies or laws; lack of enforcement of forest or land-use-related legislation. Technological barriers such as: lack of access to planting materials; lack of equipment and/or infrastructure for implementation of the technology.

Barriers related to local tradition such as: traditional knowledge or lack thereof, laws and customs, market conditions, practices; traditional equipment and technology.

Barriers due to local ecological conditions such as: degraded soil (e.g, erosion, salination, etc.); catastrophic natural and / or human-induced events (e.g., landslides, fire, etc); pervasive opportunistic species preventing regeneration of trees (e.g., grasses, weeds); unfavorable course of ecological succession; biotic pressure in terms of grazing, fodder collection, etc.

Barriers due to social conditions such as: shortage of available labor to undertake the ARR project activity; lack of skilled and/or properly trained labor force.

Barriers relating to land tenure, ownership, inheritance, and property rights, e.g.: communal land ownership with a hierarchy of rights for different stakeholders limits the incentives to undertake the ARR project activity; lack of suitable land tenure legislation and regulation to support the security of tenure; absence of clearly defined and regulated property rights in relation to natural resource products and services; formal and informal tenure systems that increase the risks of fragmentation of landholdings.

Barriers relating to markets, transport and storage; unregulated and informal markets for products and services related to the project activity prevent the transmission of effective information to project proponent(s); remoteness of ARR project activities and undeveloped road and infrastructure incur large transportation expenditures, thus eroding the competitiveness and profitability of timber and non-timber products from the ARR project activity; possibilities of large price risk due to the fluctuations in the prices of products related to the project activity over the project period in the absence of efficient markets and insurance mechanisms; absence of facilities to convert, store and add value to production from ARR project activities limits the possibilities to capture rents from the land use under the ARR project activity.

2) Provide transparent and documented evidence for the existence and significance of the identified barriers. Anecdotal evidence can be included, but alone is not sufficient proof of barriers. The type of evidence provided may include:

   a) Relevant legislation, regulatory information, or environmental/natural resource management norms, acts or rules

   b) Relevant peer-reviewed (sectoral) studies or surveys (e.g., market surveys, technology studies) undertaken by universities, research institutions, NGOs, associations, companies, bilateral/multilateral institutions etc.

   c) Relevant data from national or international statistics

   d) Documentation of relevant market data (e.g., market prices, tariffs, rules)

e) Written documentation from the company or institution developing or implementing the ARR project activity or from the project proponent, such as minutes from board meetings, correspondence, feasibility studies, financial or budgetary information

f) Written documentation of independent expert judgments from AFOLU-related government/non-government bodies or individual experts, educational institutions (e.g., universities, technical schools, training centers), professional associations and others

# 8 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

## 8.1 Baseline Emissions

### Area-based quantification

Net GHG removals in the baseline scenario are accounted by applying the crediting baseline performance benchmark value (derived in Section 6) to the calculation of net emission reductions, NGRs (Section 8.5).

### Census-based quantification

The baseline scenario is represented by the absence of planting units, and net GHG removals in the baseline scenario are equal to zero.

## 8.2 Project Emissions

### 8.2.1 General

Net GHG removals (expressed as a positive value) in the project scenario are estimated as:

$$\Delta C_{WP} = \Delta C_{WP_{biomass}} + \Delta C_{WP_{SOC}} - GHG_{WP_{bburn}} - GHG_{WP_{N_2O}} \quad (1)$$

$$\Delta C_{WP_{biomass}} = \sum_{t=1}^{T} \left( \frac{44}{12} \times \Delta C_{WP_{biomass,t}} \right) \quad (2)$$

$$\Delta C_{WP_{SOC}} = \sum_{t=1}^{T} \left( \frac{44}{12} \times \Delta C_{WP_{SOC,t}} \right) \quad (3)$$

$$GHG_{WP_{bburn}} = \sum_{t=1}^{T} GHG_{WP_{bburn,t}} \quad (4)$$

$$GHG_{WP_{N_2O}} = \sum_{t=1}^{T} GHG_{WP_{N_2O,t}} \tag{5}$$

Where:

| | |
|---|---|
| $\Delta C_{WP}$ | Net GHG removals in the project scenario up to year $T$ (t $CO_2$e) |
| $\Delta C_{WP_{biomass}}$ | Net GHG removals by biomass carbon pools in the project scenario up to year $T$ (t $CO_2$e) |
| $\Delta C_{WP_{SOC}}$ | Net GHG removals by soil organic carbon (SOC) in the project scenario up to year $T$ (t $CO_2$e) |
| $GHG_{WP_{bburn}}$ | Net GHG emissions due to biomass burning in the project scenario up to year $T$ (t $CO_2$e) |
| $GHG_{WP_{N_2O}}$ | Net GHG emissions from nitrogen fertilizer in the project scenario up to year $T$ (t $CO_2$e) |
| $\Delta C_{WP_{biomass,t}}$ | Change in carbon stock in biomass carbon pools in the project scenario in year $t$ (t C $y^{-1}$) |
| $\Delta C_{WP_{SOC,t}}$ | Average annual change in SOC stock in the project scenario in the monitoring interval ending in year $t$ (t C $y^{-1}$) |
| $GHG_{WP_{bburn,t}}$ | Net GHG emissions due to biomass burning in the project scenario in year $t$ (t $CO_2$e $y^{-1}$) |
| $GHG_{WP_{N_2O,t}}$ | Net GHG emissions from nitrogen fertilizer in the project scenario in year $t$ (t $CO_2$e $y^{-1}$) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since project start date (y) |

Changes in the carbon stock in biomass carbon pools in the project scenario are calculated using the following equation:

$$\Delta C_{WP_{biomass,t}} = \Delta C_{WP_{woody,t}} + \Delta C_{WP_{herb,t}} + \Delta C_{WP_{HWP,t}} + \Delta C_{WP_{DW,t}} + \Delta C_{WP_{LI,t}} \tag{6}$$

Where:

| | |
|---|---|
| $\Delta C_{WP_{biomass,t}}$ | Change in carbon stock in biomass carbon pools in the project scenario in year $t$ (t C $y^{-1}$) |
| $\Delta C_{WP_{woody,t}}$ | Average annual change in carbon stock in woody biomass in the project scenario in the monitoring interval ending in year $t$ (t C $y^{-1}$) |
| $\Delta C_{WP_{herb,t}}$ | Average annual change in carbon stock in herbaceous biomass in the project scenario in the monitoring interval ending in year $t$ (t C $y^{-1}$) |
| $\Delta C_{WP_{HWP,t}}$ | Average annual change in carbon stock in harvested wood products in the project scenario in the monitoring interval ending in year $t$ (t C $y^{-1}$) |

| | |
|---|---|
| $\Delta C_{WP_{DW,t}}$ | Average annual change in carbon stock in dead wood in the project scenario in the monitoring interval ending in year $t$ (t C y$^{-1}$) |
| $\Delta C_{WP_{LI,t}}$ | Average annual change in carbon stock in litter in the project scenario in the monitoring interval ending in year $t$ (t C y$^{-1}$) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since project start date (y) |

For the census-based quantification approach, excluded pools (SOC, herbaceous biomass, and litter) are assigned a value of zero in Equations (1) and (6).

### 8.2.2 Woody Biomass (Trees and Shrubs)

#### Area-based quantification

The net carbon stock change in tree biomass in the project scenario is estimated as:

$$\Delta C_{WP_{woody,t}} = A_t \times (C_{WP_{woody,t}} - C_{WP_{woody,t-\Delta t}}) \,/\, \Delta t \quad (7)$$

Where:

| | |
|---|---|
| $\Delta C_{WP_{woody,t}}$ | Average annual change in carbon stock in woody biomass in the project in the monitoring interval ending in year $t$ (t C y$^{-1}$) |
| $A_t$ | Area (per stratum, if applicable) in year $t$ (ha) |
| $C_{WP_{woody,t}}$ | Carbon stock in woody biomass in year $t$ (t C ha$^{-1}$) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the start of the project activity (y) |
| $\Delta t$ | Length of monitoring interval ending in year $t$ (y) |

$$C_{WP_{woody,t}} = C_{WP_{woody_{AB,t}}} \times (1 + R) \quad (8)$$

Where:

| | |
|---|---|
| $C_{WP_{woody,t}}$ | Carbon stock in woody[1] biomass in the project scenario in year $t$ (t C ha$^{-1}$) |
| $C_{WP_{woody_{AB,t}}}$, | Carbon stock in aboveground woody biomass in the project scenario in year $t$ (t C ha$^{-1}$) |
| $R$ | Root to shoot ratio[2] for tree or shrub (t root t shoot$^{-1}$ dry matter) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the start of the project activity (y) |

[1] Defined as plants with diameter at breast height (dbh) ≥ 5 cm

[2] Care should be taken as the root to shoot ratio may change as a function of the aboveground biomass present in year $t$ (see Table 3A1.8 in Annex 3.A1 of IPCC (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry*, IGES. Available at https://www.ipcc.ch/publication/good-practice-guidance-for-land-use-land-use-change-and-forestry/).

Where estimations are applied for different tree and/or shrub species, the sum across all the tree and/or shrub species must be calculated.

Section 8.5 provides procedures for the accounting of tree harvesting.

The change in carbon stock in woody biomass is estimated using the stock difference method.

**Pre-existing woody biomass**

Any pre-existing woody biomass is also measured and included in the above- and belowground biomass estimates. Stock change accounted for in the with-project scenario subtracts initial $t = 0$ stocks estimated immediately prior to initiation of the project activity.

Any removals of pre-existing woody biomass as part of the project activity (e.g., due to site preparation) are accounted for by calculating stock change referencing initial $t = 0$ stocks. Initial woody biomass stocks may be assumed to equal zero if the canopy cover of woody trees and shrubs, averaged across the project area, is less than 5% at $t = 0$, assessed using aerial photographs or high resolution (≤5 m) satellite imagery.

### Census-based quantification

Carbon stock change in woody biomass in the project scenario is estimated as:

$$\Delta C_{WP_{woody,t}} = \sum_{i=1}^{n} \left( C_{WP_{woody,i,t}} - C_{WP_{woody,i,t-\Delta t}} \right) \times \frac{1}{\Delta t} \quad (9)$$

Where:

| | |
|---|---|
| $\Delta C_{WP_{woody,t}}$ | Average annual change in carbon stock in woody biomass in the project scenario in the monitoring interval ending in year $t$ (t C y$^{-1}$) |
| $C_{WP_{woody,i,t}}$ | Carbon stock in woody biomass in cohort $i$ in the project scenario in year $t$ (t C) |
| $C_{WP_{woody,i,t-\Delta t}}$ | Carbon stock in woody biomass in cohort $i$ in the project scenario in year $t - \Delta t$ (t C) |
| $\Delta t$ | Time elapsed between two successive estimations ($\Delta t = t_2 - t_1$) |
| $i$ | Cohorts of planting units (1, 2, 3, …, $n$) in the project |

Carbon stock in woody biomass in the project scenario is estimated by applying the number of planting units as a scaling factor ($N$), adjusted for cumulative mortality ($M_t$) at each monitoring event.

$$C_{WP_{woody,i,t}} = N_i \times (1 - M_{i,t}) \times C_{WP_{woody_{pu,i,t}}} \quad (10)$$

Where:

| | |
|---|---|
| $C_{WP_{woody,i,t}}$ | Carbon stock in woody biomass in cohort $i$ in the project scenario in year $t$ (t C) |
| $N_i$ | Initial population size in cohort $i$ (number of planting units) |
| $M_{i,t}$ | Cumulative mortality in cohort $i$ in year $t$ (%) |
| $C_{WP_{woody_{pu,i,t}}}$ | Average carbon stock in woody biomass per planting unit ($pu$) in cohort $i$ in the project scenario in year $t$ (t C pu$^{-1}$) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the project start date (y) |

Average carbon stock in woody biomass per planting unit is calculated as:

$$C_{WP_{woody_{pu,i,t}}} = \frac{1}{n_{i,t}} \times \sum_{pu=1}^{n_{i,t}} C_{WP_{woody_{AB_{pu,i,t}}}} \times (1 + R) \quad (11)$$

Where:

| | |
|---|---|
| $C_{WP_{woody_{pu,i,t}}}$ | Average carbon stock in woody biomass per planting unit ($pu$) in cohort $i$ in the project scenario in year $t$ (t C pu$^{-1}$) |
| $n_{i,t}$ | Number of planting units sampled in cohort $i$ in year $t$ (number) |
| $C_{WP_{woody_{AB_{pu,i,t}}}}$ | Estimated carbon stock in aboveground woody biomass in sampled planting unit $pu$ in cohort $i$ in the project scenario in year $t$ (t C) |
| $R$ | Root to shoot ratio for tree or shrub (t root t shoot$^{-1}$ dry matter) |

Planting units must be representatively sampled from the census list compiled prior to sampling. Stratification (e.g., subdividing the census list into annual cohorts) may be employed to improve precision but is not required. An appropriate representative sample would be a stratified systematic sample, within each annual cohort, selecting planting units systematically with a random start from the list of unique censused planting units.

Any deliberate vegetative propagation from original planting material must be accounted for in a new cohort of planting units $j$, subject to complete census to produce a new parameter, $N_j$. New planting units attributable to vegetative propagation sourced from existing planting units must be identified based on:

1) Being of the same species,
2) Proximity to an existing planting unit (within 1 km), and
3) Attestation from a project participant.

### 8.2.3 Herbaceous Biomass

$$\Delta C_{WP_{herb,t}} = A_t \times (C_{WP_{herb,t_2}} - C_{WP_{herb,t_1}}) / \Delta t \quad (12)$$

$$C_{WP_{herb,t}} = DM_{WP_{herb,t}} \times CF_{herb} \quad (13)$$

Where:

| | |
|---|---|
| $\Delta C_{WP_{herb,t}}$ | Average annual change in carbon stock in herbaceous biomass in the project scenario in the monitoring interval ending in year $t$ (t C y$^{-1}$) |
| $A_t$ | Area (per stratum, if applicable) in year $t$ (ha) |
| $C_{WP_{herb,t}}$ | Carbon stock in herbaceous biomass in the project scenario in year $t$ (t C ha$^{-1}$) |
| $DM_{WP_{herb,t}}$ | Herbaceous biomass in the project scenario in year $t$ (t dry matter ha$^{-1}$) |
| $CF$ | Carbon fraction of biomass (t C t$^{-1}$ dry matter) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the project start date (y) |
| $\Delta t$ | Time elapsed between two successive estimations ($\Delta t = t_2 - t_1$) |

### 8.2.4 Harvested Wood Products

The procedure employs emission factors derived from Winjum et al. (1998). The stock change (inputs) to carbon in long term storage in harvested wood products in the project scenario is estimated as:

$$\Delta C_{WP_{HWP,t}} = C_{WP_{HWP,t}} / \Delta t \quad (14)$$

Where:

| | |
|---|---|
| $\Delta C_{WP_{HWP,t}}$ | Average annual change in carbon stock in harvested wood products in the project scenario in the monitoring interval ending in year $t$ (t C y$^{-1}$) |
| $C_{WP_{HWP,t}}$ | Carbon in long-term storage in harvested wood products extracted in the project scenario in the monitoring interval ending in year $t$ (t C) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the start of the project activity (y) |
| $\Delta t$ | Length of monitoring interval ending in year $t$ (y) |

**Step 1:** Identify the wood product class(es) ($ty$; defined here as sawnwood, wood-based panels, other industrial roundwood, paper and paper board, and other) that represent the anticipated end use of the extracted carbon calculated in Step 2.

**Step 2:** Calculate the biomass carbon of the volume extracted, by wood product type $ty$, from within the project boundary:

$$C_{XB,ty,t} = \sum_{j=1}^{S} \left( V_{ex,ty,j,t} \times D_j \times CF \right) \tag{15}$$

Where:

$C_{XB,ty,t}$ Extracted biomass carbon by class of wood product $ty$ in the monitoring interval ending in year $t$ (t C)

$V_{ex,ty,j,t}$ Volume of commercial timber extracted from the project area (does not include slash left onsite), by species $j$ and wood product class $ty$ in the monitoring interval ending in year $t$ ($m^3$)

$D_j$ Mean wood density of species $j$ (t dry matter $m^{-3}$)

$CF$ Carbon fraction of biomass (t C $t^{-1}$ dry matter)

$j$ Tree species (1, 2, 3, …, $S$)

$ty$ Wood product class — defined here as sawnwood (s), wood-based panels (w), other industrial roundwood (oir), paper and paper board (p), and other (o)

$t$ Time elapsed (1, 2, 3, …, $T$) since the project start date (y)

**Step 3:** Calculate the proportion of biomass carbon extracted that remains sequestered in long-term wood products:

$$C_{WP_{HWP},t} = \sum_{ty=s,w,oir,p,o} C_{XB,ty,t} \times \left(1 - WW_{ty}\right) \times \left(1 - SLF_{ty}\right) \times \left(1 - OF_{ty}\right) \tag{16}$$

Where:

$C_{WP_{HWP},t}$ Carbon in long-term storage in harvested wood products extracted in the monitoring interval ending in year $t$ (t C)

$C_{XB,ty,t}$ Extracted biomass carbon by class of wood product $ty$ in the monitoring interval ending in year $t$ (t C)

$WW_{ty}$ Wood waste; the fraction immediately emitted through mill inefficiency by class of wood product $ty$ (dimensionless)

$SLF_{ty}$ Fraction of wood products that will be emitted to the atmosphere within five years of timber harvest by class of wood product $ty$ (dimensionless)

$OF_{ty}$ Fraction of wood products that will be emitted to the atmosphere between 5 and 100 years after timber harvest by class of wood product $ty$ (dimensionless)

$ty$ Wood product class — defined here as sawnwood (s), wood-based panels (w), other industrial roundwood (oir), paper and paper board (p), and other (o)

$t$ Time elapsed (1, 2, 3, …, $T$) since the project start date (y)

### 8.2.5 Dead Wood

#### Area-based quantification

The net carbon stock change in dead wood in the project scenario is estimated as:

$$\Delta C_{WP_{DW,t}} = A_t \times (C_{WP_{DW,t_2}} - C_{WP_{DW,t_1}}) / \Delta t \qquad (17)$$

Where:

| | |
|---|---|
| $\Delta C_{WP_{DW,t}}$ | Average annual change in carbon stock in dead wood in the project scenario in the monitoring interval ending in year $t$ (t C $y^{-1}$) |
| $A_t$ | Area (per stratum, if applicable) in year $t$ (ha) |
| $C_{WP_{DW,t}}$ | Carbon stock in dead wood in year $t$ (t C $ha^{-1}$) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the start of the project activity (y) |
| $\Delta t$ | Length of monitoring interval ending in year $t$ (y) |

Dead wood may comprise two components: standing dead wood that is fully dead (i.e., absence of green leaves and green cambium) and lying dead wood. Thus, dead wood is calculated as:

$$C_{WP_{DW,t}} = (B_{SDW,t} + B_{LDW,t}) \times CF \qquad (18)$$

Where:

| | |
|---|---|
| $C_{WP_{DW,t}}$ | Mean carbon stock of dead wood in year $t$ (t C $ha^{-1}$) |
| $B_{SDW,t}$ | Biomass of standing dead wood in year $t$ (t dry matter $ha^{-1}$) |
| $B_{LDW,t}$ | Biomass of lying dead wood in year $t$ (t dry matter $ha^{-1}$) |
| $CF$ | Carbon fraction of biomass (t C $t^{-1}$ dry matter) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the start of the project activity (y) |

#### Census-based quantification

Using the census-based quantification approach, dead wood accounted for is limited to standing dead wood. The net carbon stock change in dead wood in the project scenario is estimated as:

$$\Delta C_{WP_{DW,t}} = \sum_{i=1}^{n} \left( C_{WP_{SDW,i,t}} - C_{WP_{SDW,i,t-\Delta t}} \right) \times \left( \frac{1}{\Delta t} \right) \qquad (19)$$

Where:

| | |
|---|---|
| $\Delta C_{WP_{DW,t}}$ | Average annual change in carbon stock in dead wood in the project scenario in the monitoring interval ending in year $t$ (t C y$^{-1}$) |
| $C_{WP_{SDW,i,t}}$ | Carbon stock in standing dead wood in cohort $i$ in the project scenario in year $t$ (t C) |
| $C_{WP_{SDW,i,t-\Delta t}}$ | Carbon stock in standing dead wood in cohort $i$ in the project scenario in year $t - \Delta t$ (t C) |
| $\Delta t$ | Time elapsed between two successive estimations ($\Delta t = t_2 - t_1$) |
| $i$ | Cohorts of planting units (1, 2, 3, …, $n$) in the project |

Carbon stock in standing dead wood in the project scenario is estimated by applying the number of planting units as a scaling factor ($N$) adjusted for the percentage of sampled planting units observed as standing dead at each monitoring event.

$$C_{WP_{SDW,i,t}} = N_i \times \left(\frac{n_{SDW,i,t}}{n_{i,t}}\right) \times C_{WP_{SDW,pu,i,t}} \times CF \tag{20}$$

Where:

| | |
|---|---|
| $C_{WP_{SDW,i,t}}$ | Carbon stock in standing dead wood in cohort $i$ in the project scenario in year $t$ (t C) |
| $N_i$ | Initial population size in cohort $i$ (number of planting units) |
| $n_{i,t}$ | Number of planting units sampled in cohort $i$ in year $t$ (number) |
| $n_{SDW,i,t}$ | Number of sampled planting units in cohort $i$ recorded as standing dead in the monitoring interval ending in year $t$ (number) |
| $C_{WP_{SDW,pu,i,t}}$ | Average dry mass in standing dead wood per planting unit ($pu$) observed as standing dead in cohort $i$ in the project scenario in year $t$ (t dry matter pu$^{-1}$) |
| $CF$ | Carbon fraction of biomass (t C t$^{-1}$ dry matter) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the project start date (y) |

### 8.2.6 Litter

$$\Delta C_{WP_{LI,t}} = A_t \times (C_{WP_{LI,t_2}} - C_{WP_{LI,t_1}}) / \Delta t \tag{21}$$

Two methods are provided for estimation of carbon stock in litter: a measurement-based method and a conservative default-based approach.

**Measurement-based method**

$$C_{WP_{LI,t}} = DM_{WP_{LI,t}} \times CF_{LI} \tag{22}$$

Where:

| | |
|---|---|
| $\Delta C_{WP_{LI,t}}$ | Average annual change in carbon stock in litter in the project scenario in the monitoring interval ending in year $t$ (t C y$^{-1}$) |
| $A_t$ | Area (per stratum, if applicable) in year $t$ (ha) |
| $C_{WP_{LI,t}}$ | Carbon stock in litter in the project scenario in year $t$ (t C ha$^{-1}$) |
| $DM_{WP_{LI,t}}$ | Litter dry mass in the project scenario in year $t$ (t dry matter ha$^{-1}$) |
| $CF_{LI}$ | Carbon fraction of litter (t C t$^{-1}$ dry matter) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the project start date (y) |
| $\Delta t$ | Time elapsed between two successive estimations ($\Delta t = t_2 - t_1$) |

**Conservative default factor-based method**

The default factor-based method is applicable only if litter remains in situ and is not removed from the project boundary through any type of anthropogenic activity.

$$C_{WP_{LI,t}} = C_{WP_{woody_{AB,t}}} \times DF_{LI} \quad (23)$$

Where:

| | |
|---|---|
| $C_{WP_{woody_{AB,t}}}$ | Carbon stock in aboveground woody biomass in year $t$ (t C ha$^{-1}$) |
| $DF_{LI}$ | Conservative default factor expressing carbon stock in litter as a percentage of carbon stock in aboveground woody biomass (%) |

### 8.2.7 Soil Organic Carbon

Two methods are provided for the estimation of the SOC stock: a conservative default factor-based method and a measurement-based method.

**Default factor-based method**

For the purposes of this procedure, the areas of land must be stratified according to:

1) Soil type
2) Pre-project land use (e.g., grassland, long-term cultivated cropland, short-term cultivated cropland, improved grassland, moderately degraded grassland, severely degraded grassland)
3) Pre-project management activity (e.g., full-, reduced-, no-till)
4) Pre-project inputs (e.g., use of residues, manure, fertilizers)
5) Fraction of area to be subjected to ploughing/ripping/scarification in the project:
    a) Less than or equal to 10%

b) More than 10%

6) Year of site preparation

The change in SOC stock that occurs until a steady state[3] is reached in the project scenario is estimated as follows:

For $t < t_{prep}$:

$$\Delta C_{WP_{SOC,t}} = 0 \tag{24}$$

For $t = t_{prep}$:

$$\Delta C_{WP_{SOC,t}} = A_t \times C_{WP_{SOC,LOSS}} \tag{25}$$

For $t_{prep} < t \leq t_{prep+20}$:

$$\Delta C_{WP_{SOC,t}} = A_t \times (C_{WP_{SOC,REF}} - (C_{WP_{SOC,INIT}} - C_{WP_{SOC,LOSS}})) \ / \ 20 \tag{26}$$

Under this default factor-based method, SOC stock enhancement is limited as follows:

$$\Delta C_{WP_{SOC,t}} \ / \ A_t \leq 0.8 \text{ t C ha}^{-1} \text{ y}^{-1} \tag{27}$$

Where:

| | |
|---|---|
| $\Delta C_{WP_{SOC,t}}$ | Average annual change in SOC stock in the project scenario in the monitoring interval ending in year $t$ (t C y$^{-1}$) |
| $A_t$ | Area (per stratum, if applicable) in year $t$ (ha) |
| $C_{WP_{SOC,REF}}$ | Reference SOC stock corresponding to the reference condition in native lands (i.e., non-degraded, unimproved lands under native vegetation – normally forest) by climate region and soil type applicable to the project area (t C ha$^{-1}$) |
| $C_{WP_{SOC,INIT}}$ | SOC stock at the beginning of the ARR project activity (t C ha$^{-1}$) |
| $C_{WP_{SOC,LOSS}}$ | Loss of SOC caused by soil disturbance attributable to site preparation (t C ha$^{-1}$) |
| $t_{prep}$ | Year in which first soil disturbance takes place |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the project start date (y) |

[3] This procedure assumes the following: (*i*) site preparation and planting take place within a year of each other; (*ii*) implementation of the ARR project activity increases the SOC content from the pre-project level to a level that is equal to the steady-state SOC content under native vegetation; and (*iii*) the increase in SOC content takes place at a constant rate over a period of 20 years from the year of planting.

$$C_{WP_{SOC,INIT}} = C_{WP_{SOC,REF}} \times f_{LU} \times f_{MG} \times f_{IN} \quad (28)$$

Where:

| | |
|---|---|
| $C_{WP_{SOC,INIT}}$ | SOC stock at the beginning of the ARR project activity (t C ha$^{-1}$) |
| $C_{WP_{SOC,REF}}$ | Reference SOC stock corresponding to the reference condition in native lands (i.e., non-degraded, unimproved lands under native vegetation – normally forest) by climate region and soil type applicable to the project area (t C ha$^{-1}$) |
| $f_{LU}$ | Stock change factor for type of land use (dimensionless) |
| $f_{MG}$ | Stock change factor for management regime (dimensionless) |
| $f_{IN}$ | Stock change factor for input of organic matter (dimensionless) |

The values of $C_{WP_{SOC,REF}}$, $f_{LU}$, $f_{MG}$, and $f_{IN}$ must be selected from the following sources, listed in descending order of preference:

1) Peer-reviewed scientific publications relating to local conditions
2) Relevant national inventories (e.g., soil inventory, forest inventory, or GHG inventory)
3) Country/region-specific data
4) Parameter tables for $C_{WP_{SOC,REF}}$, $f_{LU}$, $f_{MG}$, and $f_{IN}$ in Section 9.1

For areas (strata) subjected to ploughing/ripping/scarification attributable to the project activity within the first five years of initial site preparation, and for which the total area disturbed is greater than 10% of the project area, the following carbon loss must be accounted:

$$C_{WP_{SOC,LOSS}} = C_{WP_{SOC,INIT}} \times 0.1$$

For all other areas:

$$C_{WP_{SOC,LOSS}} = 0$$

**Measurement-based method**

For the measurement-based method, the change in SOC stock in the project scenario is estimated as:

$$\Delta C_{WP_{SOC,t}} = A_t \times (C_{WP_{SOC,t_2}} - C_{WP_{SOC,t_1}}) / \Delta t \quad (29)$$

Where:

| | |
|---|---|
| $\Delta C_{WP_{SOC,t}}$ | Average annual change in SOC stock in the project scenario in the monitoring interval ending in year $t$ (t C y$^{-1}$) |

| | |
|---|---|
| $A_t$ | Area (per stratum, if applicable) in year $t$ (ha) |
| $C_{WP_{SOC,t}}$ | SOC stock in year $t$ (t C ha$^{-1}$) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the start of the project activity (y) |
| $\Delta t$ | Length of monitoring interval ending in year $t$ (y) |

### 8.2.8 Non-CO2 Emissions from Biomass Burning

#### Area-based quantification

$$GHG_{WP_{bburn,t}} = A_{burn,t} \times \left( \sum_{g=1}^{G} GWP_g \times EF_g \times B_{WP,t} \times COMF \times 10^{-3} \right) \times \frac{12}{44} \quad (30)$$

Where:

| | |
|---|---|
| $GHG_{WP_{bburn,t}}$ | Net GHG emissions due to biomass burning in the project scenario in year $t$ (t $CO_2$e y$^{-1}$) |
| $A_{burn,t}$ | Area burnt in year $t$ (ha) |
| $GWP_g$ | Global warming potential for gas $g$ (dimensionless) |
| $EF_g$ | Emission factor for gas $g$ (kg t$^{-1}$ dry matter burnt) |
| $B_{WP,t}$ | Aboveground biomass stock before burning in the project scenario in year $t$ (t dry matter ha$^{-1}$) |
| $COMF$ | Combustion factor (dimensionless) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the start of the project activity (y) |
| $g$ | Greenhouse gases (1, ..., $G$) (methane and nitrous oxide) (dimensionless) |
| $\frac{12}{44}$ | Inverse ratio of molecular weight of $CO_2$ to carbon (t $CO_2$e t C$^{-1}$) |

The average aboveground carbon stock before burning is estimated as follows:

$$B_{WP,t} = (C_{WP_{woody_{AB,t}}} + C_{WP_{herb,t}} + C_{WP_{DW,t}} + C_{WP_{LI,t}}) \times (1/CF) \quad (31)$$

Where:

| | |
|---|---|
| $B_{WP,t}$ | Aboveground biomass stock before burning in the project scenario in year $t$ (t dry matter ha$^{-1}$) |
| $C_{WP_{woody_{AB,t}}}$ | Carbon stock in aboveground woody biomass in the project scenario in year $t$ (t C ha$^{-1}$) |
| $C_{WP_{herb,t}}$ | Carbon stock in herbaceous biomass in the project scenario in year $t$ (t C ha$^{-1}$) |

| | |
|---|---|
| $C_{WP_{DW,t}}$ | Carbon stock in dead wood in year $t$ (t C ha$^{-1}$) |
| $C_{WP_{LI,t}}$ | Carbon stock in litter in the project scenario in year $t$ (t C ha$^{-1}$) |
| $CF$ | Carbon fraction, set at 0.5 (t C t$^{-1}$ dry matter) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the start of the project activity (y) |

### Census-based quantification

$$GHG_{WP_{bburn,t}} = \left(\sum_{g=1}^{G} GWP_g \times EF_g \times B_{WP,t} \times COMF \times 10^{-3}\right) \times \frac{12}{44} \quad (32)$$

Where:

| | |
|---|---|
| $GHG_{WP_{bburn,t}}$ | Net GHG emissions due to biomass burning in the project scenario in year $t$ (t $CO_2$e y$^{-1}$) |
| $GWP_g$ | Global warming potential for gas $g$ (dimensionless) |
| $EF_g$ | Emission factor for gas $g$ (kg t$^{-1}$ dry matter burnt) |
| $B_{WP,t}$ | Aboveground biomass stock of planting units subject to burning in the project scenario in the monitoring interval ending in year $t$ (t dry matter) |
| $COMF$ | Combustion factor (dimensionless) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the start of the project activity (y) |
| $g$ | Greenhouse gases (1, ..., $G$) (methane and nitrous oxide) (dimensionless) |
| $\frac{12}{44}$ | Inverse ratio of molecular weight of $CO_2$ to carbon (t $CO_2$e t C$^{-1}$) |

The aboveground carbon stock of planting units subject to burning (estimated from measurements prior to the burn) is estimated as follows, applying the number of planting units as a scaling factor ($N$) adjusted for the percentage of sampled planting units observed to be visibly burned at each monitoring event.

$$B_{WP,t} = N_i \times \left(\frac{n_{burn_{i,t}}}{n_{i,t}}\right) \times C_{WP_{burn_{pu,i,t-\Delta t}}} \quad (33)$$

Where:

| | |
|---|---|
| $B_{WP,t}$ | Aboveground biomass stock of planting units subject to burning in the project scenario in the monitoring interval ending in year $t$ (t dry matter) |
| $N_i$ | Initial population size in cohort $i$ (number of planting units) |
| $n_{i,t}$ | Number of planting units sampled in cohort $i$ in year $t$ (number) |
| $n_{burn_{i,t}}$ | Number of sampled planting units in cohort $i$ recorded as burned in the monitoring interval ending in year $t$ (number) |

| | |
|---|---|
| $C_{WP_{burn_{pu,i,t-\Delta t}}}$ | Average dry mass per planting unit ($pu$) observed as burned in cohort $i$ in the project scenario in year $t$, measured in year $t - \Delta t$ (t dry matter $pu^{-1}$) |
| $t$ | Time elapsed (1, 2, 3, …, $T$) since the project start date (y) |
| $\Delta t$ | Length of monitoring interval ending in year $t$ (y) |

### 8.2.9 Nitrous Oxide Emissions from Fertilizer Application

Where nitrogen fertilizer is applied due to the project activity, nitrous oxide emissions are calculated as:

$$GHG_{WP_{N_2O,t}} = A_{fert,t} \times (CO2e_{Ndirect,t} + CO2e_{Nindirect,t}) \quad (34)$$

Where:

| | |
|---|---|
| $GHG_{WP_{N_2O,t}}$ | Net GHG emissions from nitrogen fertilizer in the project scenario in year $t$ (t $CO_2$e $y^{-1}$) |
| $A_{fert,t}$ | Area on which nitrogen fertilizer is applied in year $t$ (ha) |
| $CO2e_{Ndirect,t}$ | Direct nitrous oxide emissions due to fertilizer use in the project scenario in year $t$ (t $CO_2$e $ha^{-1}$) |
| $CO2e_{Nindirect,t}$ | Indirect nitrous oxide emissions due to fertilizer use in the project scenario in the monitoring interval ending in year $t$ (t $CO_2$e $ha^{-1}$) |

$$CO2e_{Ndirect,t} = \left(F_{WP,SN,i,t} + F_{WP,ON,i,t}\right) \times EF_{Ndirect} \times \frac{44}{28} \times GWP_{N_2O} \quad (35)$$

$$F_{WP,SN,i,t} = M_{WP,SF,i,t} \times NC_{WP,SF,i,t}$$

$$F_{WP,ON,i,t} = M_{WP,OF,i,t} \times NC_{WP,OF,i,t}$$

Where:

| | |
|---|---|
| $CO2e_{Ndirect,t}$ | Direct nitrous oxide emissions due to fertilizer use in the project scenario in year $t$ (t $CO_2$e $ha^{-1}$) |
| $F_{WP,SN,i,t}$ | Synthetic N fertilizer applied in the project scenario in year $t$ (t N $ha^{-1}$) |
| $F_{WP,ON,i,t}$ | Organic N fertilizer applied in the project scenario in year $t$ (t N $ha^{-1}$) |
| $M_{WP,SF,i,t}$ | Mass of synthetic fertilizer containing N applied in the project scenario in year $t$ (t fertilizer $ha^{-1}$) |
| $M_{WP,OF,i,t}$ | Mass of organic fertilizer containing N applied in the project scenario in year $t$ (t fertilizer $ha^{-1}$) |

| | |
|---|---|
| $NC_{WP,SF,i,t}$ | N content of synthetic fertilizer applied in the project scenario in year $t$ (t N t fertilizer$^{-1}$) |
| $NC_{WP,OF,i,t}$ | N content of organic fertilizer applied in the project scenario in year $t$ (t N t fertilizer$^{-1}$) |
| $EF_{Ndirect}$ | Emission factor for nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments, and crop residues (t $N_2O$-N t N applied$^{-1}$) |
| $GWP_{N_2O}$ | Global warming potential for $N_2O$ (dimensionless) |

$$CO2e_{Nindirect,t} = Nfert_{WP,volat,i,t} + Nfert_{WP,leach,i,t} \quad (36)$$

$$Nfert_{WP,volat,i,t} = \left[\left(F_{WP,SN,i,t} \times Frac_{GASF}\right) + \left(F_{WP,ON,i,t} \times Frac_{GASM}\right)\right] \times EF_{Nvolat} \times \frac{44}{28} \times GWP_{N_2O}$$

$$Nfert_{WP,leach,i,t} = \left(F_{WP,SN,i,t} + F_{WP,ON,i,t}\right) \times Frac_{LEACH} \times EF_{Nleach} \times \frac{44}{28} \times GWP_{N_2O}$$

Where:

| | |
|---|---|
| $CO2e_{Nindirect,t}$ | Indirect nitrous oxide emissions due to fertilizer use in the project scenario in the monitoring period ending in year $t$ (t $CO_2$e ha$^{-1}$) |
| $Nfert_{WP,volat,i,t}$ | Indirect nitrous oxide emissions produced from atmospheric deposition of N volatilized due to nitrogen fertilizer use in the project scenario in year $t$ (t $CO_2$e ha$^{-1}$) |
| $Nfert_{WP,leach,i,t}$ | Indirect nitrous oxide emissions produced from leaching and runoff of N, in regions where leaching and runoff occurs, due to nitrogen fertilizer use in the project scenario in year $t$ (t $CO_2$e ha$^{-1}$). Value = 0 where average annual precipitation is less than potential evapotranspiration, unless subject to irrigation |
| $F_{WP,SN,i,t}$ | Synthetic N fertilizer applied in the project scenario in year $t$ (t N ha$^{-1}$) |
| $F_{WP,ON,i,t}$ | Organic N fertilizer applied in the project scenario in year $t$ (t N ha$^{-1}$) |
| $Frac_{GASF}$ | Fraction of all synthetic N added to soils that volatilizes as $NH_3$ and $NO_x$ (dimensionless) |
| $Frac_{GASM}$ | Fraction of all organic N added to soils that volatilizes as $NH_3$ and $NO_x$ (dimensionless) |
| $Frac_{LEACH}$ | Fraction of N (synthetic and organic) added to soils that is lost through leaching and runoff, in regions where leaching and runoff occurs (dimensionless) |

| | |
|---|---|
| $EF_{Nvolat}$ | Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces (t $N_2O$-N (t $NH_3$-N + $NO_x$-N volatilized)$^{-1}$) |
| $EF_{Nleach}$ | Emission factor for nitrous oxide emissions from leaching and runoff (t $N_2O$-N t $N^{-1}$ leached and runoff) |
| $GWP_{N_2O}$ | Global warming potential for $N_2O$ (dimensionless) |

#### 8.2.10 Guidance on Ex-ante Estimation of Project Net GHG removals

For the purpose of the ex-ante (projected) estimation of carbon stocks in a reforestation project scenario, carbon stocks of pools other than trees may be estimated as zero.

For the ex-ante estimation of tree biomass, tree growth and stand development models, or published data relevant to the project area (e.g., chronosequences), may be used. For herbaceous biomass, growth models and published data may be used.

Models and published data must be from systems that are in the same or a similar region as the project area, share similar geomorphic, hydrologic, and biological properties, and are under similar management regimes.

Ex-ante estimation is not subjected to uncertainty control, although the project proponent should use the best available data and models that apply to the project site and to the tree, shrub, or herbaceous species.

## 8.3 Leakage

Emissions from leakage are accounted for using the current version of the *Module for Estimating Leakage from ARR Activities*, to derive a Leakage Discount Factor (LDF) at the project start date.

## 8.4 Uncertainty

Uncertainty associated with sample error is quantified and accounted for. Measurement error is addressed through application of the quality assurance/quality control (QA/QC) procedures detailed in Section 9.2. Estimation of emission sources from biomass burning and nitrogen fertilizer apply conservative parameters and associated uncertainty is set to zero.

### Area-based quantification

Uncertainty in area estimation is assumed to be zero and is addressed via use of complete (and accurate) GIS boundaries of the project area, and applying QA/QC procedures specified in the parameter table for $A_t$. The performance benchmark is assumed to have zero uncertainty.

Uncertainty is calculated by propagating errors associated with estimates of included pools as:

$$UNC = MIN(100\%, MAX\ (0, \left(\sum_{p=1}^{n} (U_p \times C_p)^2\right)^{\frac{1}{2}} \times \left(\frac{1}{\Delta C_{WP_{biomass}} + \Delta C_{WP_{SOC}}}\right) - 15\%)) \quad (37)$$

Where:

| | |
|---|---|
| $UNC$ | Uncertainty (%) |
| $\Delta C_{WP_{biomass}}$ | Net GHG removals by biomass carbon pools in the project scenario up to year $T$ (t $CO_2$e) |
| $\Delta C_{WP_{SOC}}$ | Net GHG removals by SOC in the project scenario up to year $T$ (t $CO_2$e) |
| $U_{p,t}$ | Percentage uncertainty (expressed as 95% confidence interval, as a percentage of the mean) in carbon stock estimate of pool $p$ (representing woody biomass, herbaceous biomass, dead wood, harvested wood products, litter, and SOC) in the project scenario in year $t$ (%) |
| $C_{p,t}$ | Carbon stock estimate of pool $p$ (representing woody biomass, herbaceous biomass, dead wood, harvested wood products, litter, and SOC) in the project scenario in year $t$ (t $CO_2$e) |

### Census-based quantification

Uncertainty in parameter $N$, population size, is assumed to be zero and is addressed via the requirement for complete census of planting units. The project method baseline, equal to zero (absence of planting units), is assumed to have zero uncertainty.

Uncertainty is calculated by propagating errors associated with estimates of included pools as:

$$UNC = MIN(100\%, MAX\ (0, \left(\sum_{p=1}^{n} (U_p \times C_p)^2\right)^{\frac{1}{2}} \times \left(\frac{1}{\Delta C_{WP_{biomass}}}\right) - 15\%)) \quad (38)$$

Where:

| | |
|---|---|
| $UNC$ | Uncertainty (%) |
| $\Delta C_{WP_{biomass}}$ | Net GHG removals by biomass carbon pools in the project scenario up to year $T$ (t $CO_2$e) |
| $U_{p,t}$ | Percentage uncertainty (expressed as 95% confidence interval, as a percentage of the mean) in carbon stock estimate of pool $p$ (representing woody biomass, dead wood, and harvested wood products) in the project scenario in year $t$ (%) |

| | |
|---|---|
| $C_{p,t}$ | Carbon stock estimate of pool $p$ (representing woody biomass, dead wood, and harvested wood products) in the project scenario in year $t$ (t $CO_2$e) |

## 8.5 Net GHG Emission Reductions and Removals

### Area-based quantification

$$NGR = \Delta C_{WP} \times (1 - PB_t) \times (1 - LDF) \times (1 - UNC) \quad (39)$$

Where:

| | |
|---|---|
| $NGR$ | Net GHG removals due to the project activity up to year $T$ (t $CO_2$e) |
| $\Delta C_{WP}$ | Net GHG removals in the project scenario up to year $T$ (t $CO_2$e) |
| $PB_t$ | Performance benchmark up to year $T$ (%) |
| $LDF$ | Leakage discount factor (%) |
| $UNC$ | Uncertainty (%) |

### Census-based quantification

Net GHG removals using census-based quantification are calculated with removals in the baseline scenario implicitly set equal to zero.

$$NGR = \Delta C_{WP} \times (1 - LDF) \times (1 - UNC) \quad (40)$$

Where:

| | |
|---|---|
| $NGR$ | Net GHG removals from the project activity up to year $T$ (t $CO_2$e) |
| $\Delta C_{WP}$ | Net GHG removals in the project scenario up to year $T$ (t $CO_2$e) |
| $LDF$ | Leakage discount factor (%) |
| $UNC$ | Uncertainty (%) |

**Accounting for tree harvesting**

Where project activities include harvesting, the maximum number of GHG credits generated by these activities over the crediting period must not exceed the long-term average GHG benefit. Where a commercial tree species is planted as part of the project activity, or the project proponent is a forest management entity, it is conservatively assumed that the project area will be subject to harvest. The long-term average is calculated as follows, to align with the current version of the *VCS Methodology Requirements*:

$$LA = \frac{\sum_{t=1}^{n} NGR_t}{n} \quad (41)$$

Where:

| | |
|---|---|
| $LA$ | Long-term average GHG benefit in the project,[4] with harvesting in time period $n$ (t $CO_2$e) |
| $NGR_t$ | Total net GHG removals by the project activity in year $t$ (t $CO_2$e) |
| $n$ | Total number of years in the established time period; this period includes the last cut, even if that falls outside the crediting period (y) |

To determine the number of buffer credits to be withheld, the long-term average change in carbon stock is calculated as follows:

$$LC = \frac{A_t \times \sum_{t=1}^{n}(\Delta C_{WP_{biomass,t}} + \Delta C_{WP_{SOC,t}}) - A_t \times \sum_{t=1}^{n}(\Delta C_{BSL_{biomass,t}} + \Delta C_{BSL_{SOC,t}})}{n} \quad (42)$$

Where:

| | |
|---|---|
| $LC$ | Long-term average change in carbon stock in the project scenario with harvesting in time period $n$ (t $CO_2$e) |
| $A_t$ | Area in year $t$ (ha) |
| $\Delta C_{WP_{biomass,t}}$ | Change in carbon stock in the biomass carbon pools in the project scenario in year $t$ (t C $ha^{-1}$ $y^{-1}$) |
| $\Delta C_{WP_{SOC,t}}$ | Average annual change in soil carbon stock in the project scenario in the monitoring interval ending year $t$ (t C $ha^{-1}$ $y^{-1}$) |
| $\Delta C_{BSL_{biomass,t}}$ | Change in carbon stock in the biomass carbon pools in the baseline scenario in year $t$ (t C $ha^{-1}$ $y^{-1}$) |
| $\Delta C_{BSL_{SOC,t}}$ | Change in soil carbon stock in the baseline scenario in year $t$ (t C $ha^{-1}$ $y^{-1}$) |
| $n$ | Total number of years in the established time period; this period includes the last cut, even if that falls outside the crediting period (y) |

# 9 MONITORING

## 9.1 Data and Parameters Available at Validation

| Data / Parameter | $A_t$ |
|---|---|

[4] $LA$ must be re-calculated at each verification, based on monitoring data (see Section 9.2).

| | |
|---|---|
| Data unit | ha |
| Description | Project area in year $t$ |
| Equations | (7), (12), (17), (21), (25), (26), (27), (29), (42) |
| Source of data | Calculated from GIS data |
| Value applied | |
| Justification of choice of data or description of measurement methods and procedures applied | Delineation of the project area may use a combination of GIS coverage, ground survey data with GPS, remote imagery (satellite or aerial photographs), and other appropriate data. Any imagery or GIS datasets used must be geo-registered by referencing corner points, clear landmarks, or other intersection points. |
| Purpose of data | Reference for area measures |
| Comments | The project activity may contain more than one discrete area of land. Each discrete area of land must have a unique geographic identification.<br>Where the project area at the project start date is not homogeneous, stratification may be carried out to improve the accuracy and precision of estimates of carbon stock and GHG flux. |

| Data / Parameter | $R_j$ |
|---|---|
| Data unit | t root dry matter $t^{-1}$ shoot dry matter |
| Description | Root to shoot ratio appropriate to species or forest type/biome; note that as defined here, root to shoot ratio is applied as a belowground biomass per hectare to aboveground biomass per hectare ratio (not on a per stem basis) |
| Equations | (8), (11) |
| Source of data | The source of data must be chosen from the following sources, listed in descending order of preference:<br>1) Detailed data collected using common practices for root sampling in the area<br>2) Published study specific to project region and vegetation community |

3) Global forest type-specific or eco-region-specific value (e.g., from the *IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry*[5])

**Root to shoot ratios for tropical and subtropical forests**[6]

| Domain | Ecological zone | Aboveground biomass (t ha$^{-1}$) | Root-to-shoot ratio | Range |
|---|---|---|---|---|
| Tropical | Tropical rainforest | <125 | 0.20 | 0.09–0.25 |
| | | >125 | 0.24 | 0.22–0.33 |
| | Tropical dry forest | <20 | 0.56 | 0.28–0.68 |
| | | >20 | 0.28 | 0.27–0.28 |
| Sub-tropical | Sub-tropical humid forest | <125 | 0.20 | 0.09–0.25 |
| | | >125 | 0.24 | 0.22–0.33 |
| | Sub-tropical dry forest | <20 | 0.56 | 0.28–0.68 |
| | | >20 | 0.28 | 0.27–0.28 |

| | |
|---|---|
| Value applied | N/A |
| Justification of choice of data or description of measurement methods and procedures applied | N/A |
| Purpose of data | Calculation of baseline emissions<br>Calculation of project emissions |
| Comments | Guidelines for conservative choice of default values: |

[5] Intergovernmental Panel on Climate Change (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry*, IGES. https://www.ipcc.ch/publication/good-practice-guidance-for-land-use-land-use-change-and-forestry/
[6] Modified from Table 4.4, Chapter 4, Volume 4 in Intergovernmental Panel on Climate Change (2006). *IPCC Guidelines for National Greenhouse Gas Inventories*, IGES. https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

| | |
|---|---|
| | 1) Where, in the sources of data listed above, default data are available for conditions that are similar to the project (similar forest or vegetation type, same climatic zone), then mean values of default data may be used and considered conservative.<br>2) Global values may be selected from Table 4.4 (modified as given above) of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, by choosing a climatic zone and forest type that most closely match the project circumstances. |

| Data / Parameter | $CF$ |
|---|---|
| Data unit | t C t dry matter$^{-1}$ |
| Description | Carbon fraction of biomass (dry matter) |
| Equations | (15), (18), (20) |
| Source of data | IPCC default value |
| Value applied | 0.47 |
| Justification of choice of data or description of measurement methods and procedures applied | IPCC is a reputable source approved by the VCS. |
| Purpose of data | Calculation of project emissions |
| Comments | N/A |

| Data / Parameter | $D_j$ |
|---|---|
| Data unit | t dry matter m$^{-3}$ |
| Description | Basic wood density of species $j$ |
| Equations | (15) |
| Source of data | Datasets or literature |
| Value applied | N/A |

| | |
|---|---|
| Justification of choice of data or description of measurement methods and procedures applied | Values for $D_j$ can be taken from tables used in local or regional timber and forest industries, or from peer-reviewed literature applicable to the region. If no species-specific values are available, the average value across all species can be used and increased by 20% to ensure conservative estimates in the baseline, or decreased by 20% to ensure conservative estimates in the project scenario.<br>Data must be chosen from the following sources, listed in descending order of preference:<br>1) National values specific to a species or group of species (e.g., from national GHG inventory)<br>2) Values, specific to a species or group of species, from neighboring countries with similar conditions<br>3) Global values specific to a species or group of species (e.g., from the *IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry*[7]) |
| Purpose of data | Calculation of baseline emissions<br>Calculation of project emissions |
| Comments | N/A |

| | |
|---|---|
| Data / Parameter | $EF_{N_2O,burn}$ |
| Data unit | g $N_2O$ kg dry biomass$^{-1}$ |
| Description | Emission factor for $N_2O$ emissions from burning vegetation |
| Equations | (30), (32) |
| Source of data | The project proponent may use factors that have been determined for grassland vegetation. A suitable $EF_{N_2O}$ value is 0.21, taken from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.[8] |
| Value applied | N/A |
| Justification of choice of data or description of | Nitrous oxide emission factors for the combustion of herbaceous wetland vegetation are not currently available in scientific literature. However, these emissions are expected to be similar to those from grassland vegetation. |

[7] Intergovernmental Panel on Climate Change (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry*, IGES. https://www.ipcc.ch/publication/good-practice-guidance-for-land-use-land-use-change-and-forestry/
[8] Table 2.5, Chapter 2, Volume 4 in Intergovernmental Panel on Climate Change (2006). *IPCC Guidelines for National Greenhouse Gas Inventories*, IGES. https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

| | |
|---|---|
| measurement methods and procedures applied | |
| Purpose of Data | Calculation of project emissions |
| Comments | N/A |

| Data / Parameter | $EF_{CH_4,burn}$ |
|---|---|
| Data unit | g $CH_4$ $kg^{-1}$ dry biomass |
| Description | Emission factor for $CH_4$ emissions from burning vegetation |
| Equations | (30), (32) |
| Source of data | The project proponent may use factors that have been determined for grassland vegetation. A suitable $EF_{CH_4}$ value is 2.3, taken from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.[9] |
| Value applied | N/A |
| Justification of choice of data or description of measurement methods and procedures applied | |
| Purpose of data | Calculation of project emissions |
| Comments | N/A |

| Data / Parameter | $N_i$ |
|---|---|
| Data unit | Number of planting units |
| Description | Initial population size of cohort $i$ |
| Equations | (10), (20), (33) |
| Source of data | Complete census/enumeration |

[9] Ibid.

| | |
|---|---|
| Value applied | The original population size, $N$, is established via administering and recording an initial complete census of all planting units. For each planting unit, the following must be recorded:<br>1) Unique ID<br>2) Geo-referenced point of the location<br>3) Year planted |
| Justification of choice of data or description of measurement methods and procedures applied | |
| Purpose of Data | Calculation of project emissions |
| Comments | Planting units must be clearly defined (e.g., tree, shrub, bamboo clump) and identifiable in the field. |

| | |
|---|---|
| Data / Parameter | $GWP_{CH_4}$ |
| Data unit | Dimensionless |
| Description | Global warming potential of methane |
| Equations | (30), (32) |
| Source of data | IPCC Fifth Assessment Report[10] |
| Value applied | 28 |
| Justification of choice of data or description of measurement methods and procedures applied | The *VCS Standard* requires that $CH_4$ is converted to $CO_2e$ using the 100-year global warming potential derived from the most recent IPCC Assessment Report. |
| Purpose of data | Calculation of project emissions |
| Comments | |

| | |
|---|---|
| Data / Parameter | $GWP_{N_2O}$ |
| Data unit | Dimensionless |

[10] Intergovernmental Panel on Climate Change (2014) *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Pachauri, R. K. & Meyer, L. A. (Eds.). IPCC, Geneva, Switzerland. https://www.ipcc.ch/report/ar5/syr/

| | |
|---|---|
| Description | Global warming potential of nitrous oxide |
| Equations | (30), (32), (35), (36) |
| Source of data | IPCC Fifth Assessment Report[11] |
| Value applied | 265 |
| Justification of choice of data or description of measurement methods and procedures applied | The *VCS Standard* requires that $N_2O$ is converted to $CO_2e$ using the 100-year global warming potential derived from the most recent IPCC Assessment Report. |
| Purpose of data | Calculation of project emissions |
| Comments | |

| | |
|---|---|
| Data / Parameter | $EF_{Ndirect}$ |
| Data unit | t $N_2O$-N t N applied$^{-1}$ |
| Description | Emission factor for direct nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments, and crop residues |
| Equations | (35) |
| Source of data | *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*[12] |
| Value applied | 0.01 |
| Justification of choice of data or description of measurement methods and procedures applied | See source of data above |
| Purpose of data | Calculation of project emissions |
| Comments | Emission factor applicable to N additions from mineral fertilizers, organic amendments, and crop residues. |

[11] Ibid.
[12] Table 11.1, Chapter 11, Volume 4 in Intergovernmental Panel on Climate Change (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

| | |
|---|---|
| Data / Parameter | $Frac_{GASF}$ |
| Data unit | Dimensionless |
| Description | Fraction of all synthetic N added to soils that volatilizes as $NH_3$ and $NO_x$ |
| Equations | (36) |
| Source of data | *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*[13] |
| Value applied | 0.1 |
| Justification of choice of data or description of measurement methods and procedures applied | See source of data above |
| Purpose of data | Calculation of project emissions |
| Comments | None |

| | |
|---|---|
| Data / Parameter | $Frac_{GASM}$ |
| Data unit | Dimensionless |
| Description | Fraction of all organic N added to soils that volatilizes as $NH_3$ and $NO_x$ |
| Equations | (36) |
| Source of data | *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*[14] |
| Value applied | 0.3 |
| Justification of choice of data or description of measurement methods and procedures applied | See source of data above |
| Purpose of data | Calculation of project emissions |

[13] Table 11.3, Chapter 11, Volume 4 in Intergovernmental Panel on Climate Change (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html
[14] Ibid.

| | |
|---|---|
| Comments | None |

| | |
|---|---|
| Data / Parameter | $EF_{Nvolat}$ |
| Data unit | t $N_2O$-N (t $NH_3$-N + NOx-N volatilized)$^{-1}$ |
| Description | Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces |
| Equations | (36) |
| Source of data | *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*[15] |
| Value applied | 0.01 |
| Justification of choice of data or description of measurement methods and procedures applied | See source of data above |
| Purpose of data | Calculation of project emissions |
| Comments | None |

| | |
|---|---|
| Data / Parameter | $Frac_{LEACH}$ |
| Data unit | Dimensionless |
| Description | Fraction of (synthetic and organic) N added to soils that is lost through leaching and runoff |
| Equations | (36) |
| Source of data | *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*[16] |
| Value applied | 0.3 |
| Justification of choice of data or description of measurement methods and procedures applied | See source of data above |

[15] Ibid.
[16] Ibid.

| | |
|---|---|
| Purpose of data | Calculation of project emissions |
| Comments | None |

| | |
|---|---|
| Data / Parameter | $EF_{Nleach}$ |
| Data unit | t $N_2O$-N t $N^{-1}$ leached and runoff |
| Description | Emission factor for nitrous oxide emissions from leaching and runoff |
| Equations | (36) |
| Source of data | *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*[17] |
| Value applied | 0.0075 |
| Justification of choice of data or description of measurement methods and procedures applied | See source of data above |
| Purpose of data | Calculation of project emissions |
| Comments | None |

| | |
|---|---|
| Data / Parameter | $OF_{ty}$ |
| Data unit | Dimensionless |
| Description | The fraction of wood products that will be emitted to the atmosphere between 5 and 100 years after production, by class of wood product $ty$ |
| Equations | (16) |
| Source of data | Winjum et al. (1998)[18] |
| Value applied | |

[17] Ibid.
[18] Winjum, J. K., Brown, S., & Schlamadinger, B. (1998). Forest harvests and wood products: Sources and sinks of atmospheric carbon dioxide. *Forest Science*, *44*(2), 272–284. https://doi.org/10.1093/forestscience/44.2.272

| | |
|---|---|
| Justification of choice of data or description of measurement methods and procedures applied | Winjum et al. (1998) give annual oxidation fractions for each class of wood products split by forest region (boreal, temperate, and tropical). This methodology projects these fractions over 95 years to give the additional proportion ($OF$ value) that is oxidized from the fifth to the hundredth year after initial harvest. |
| Purpose of data | |
| Comments | |

| Wood Product Class | $OF$ | | |
|---|---|---|---|
| | Boreal | Temperate | Tropical |
| Sawnwood | 0.38 | 0.62 | 0.85 |
| Wood-based panels | 0.62 | 0.85 | 0.98 |
| Other industrial roundwood | 0.85 | 0.98 | 1.00 |
| Paper and paper board | 0.38 | 0.62 | 1.00 |

| | |
|---|---|
| Data / Parameter | $SLF_{ty}$ |
| Data unit | Dimensionless |
| Description | Fraction of wood products that will be emitted to the atmosphere within five years of production by class of wood product $ty$ |
| Equations | (16) |
| Source of data | Winjum et al. (1998)[19] |
| Value applied | |
| Justification of choice of data or description of measurement methods and procedures applied | Winjum et al. (1998) give the following internationally applicable proportions for wood products with short-term (<5 years) uses after which they are retired and oxidized:<br>Sawnwood 0.2<br>Wood-based panels 0.1<br>Other industrial roundwood 0.3<br>Paper and paper board 0.4 |

[19] Ibid.

| | |
|---|---|
| | This methodology makes the assumption that all other classes of wood products, and products for which the wood product class $ty$ is unknown, are 100% oxidized within five years.<br>Therefore, $SLF$ by wood product class is equal to: |
| Purpose of data | |
| Comments | |

| Wood Product Class | $SLF$ |
|---|---|
| Sawnwood | 0.2 |
| Wood-based panels | 0.1 |
| Other industrial roundwood | 0.3 |
| Paper and paper board | 0.4 |
| Other classes of wood products | 1.0 |

| Data / Parameter | $WW_{ty}$ |
|---|---|
| Data unit | Dimensionless |
| Description | Fraction of extracted biomass effectively emitted to the atmosphere during production by class of wood product $ty$ |
| Equations | (16) |
| Source of data | Winjum et al. (1998)[20] |
| Value applied | |
| Justification of choice of data or description of measurement methods and procedures applied | Winjum et al. (1998) indicate that the proportion of extracted biomass that is oxidized (through burning or decay) from the production of commodities is equal to 19% for developed countries and 24% for developing countries. $WW$ is therefore equal to $C_{XB,ty}$ multiplied by 0.19 for developed countries and by 0.24 for developing countries. |
| Purpose of data | |
| Comments | |

[20] Ibid.

| | |
|---|---|
| Data / Parameter | $CF_{LI}$ |
| Data unit | t C t$^{-1}$ dry matter |
| Description | Carbon fraction of dry matter of litter |
| Equations | (22) |
| Source of data | Value taken from the *IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry*[21] |
| Value applied | 0.37 |
| Justification of choice of data or description of measurement methods and procedures applied | IPCC is a reputable source approved by the VCS. |
| Purpose of data | Calculation of project emissions |
| Comments | N/A |

| | |
|---|---|
| Data / Parameter | $DF_{LI}$ |
| Data unit | % |
| Description | Conservative default factor expressing carbon stock in litter as a percentage of carbon stock in aboveground tree biomass |
| Equations | (23) |
| Source of data | Taken from the CDM *A/R Methodological Tool – Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities*,[22] where the table is conservatively derived from various literature sources |
| Value applied | |

[21] Section 3.2.1.2.1.1, Chapter 3 in Intergovernmental Panel on Climate Change (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry*, IGES. https://www.ipcc.ch/publication/good-practice-guidance-for-land-use-land-use-change-and-forestry/

[22] Clean Development Mechanism (2015). *AR-TOOL12: A/R Methodological Tool – Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities*. https://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-12-v1.1.0.pdf/history_view

| | |
|---|---|
| Justification of choice of data or description of measurement methods and procedures applied | <table><tr><th>Biome</th><th>Elevation (m)</th><th>Precipitation (mm y-1)</th><th>$DF_{LI}$ (%)</th></tr><tr><td>Tropical</td><td><2000</td><td><1000</td><td>4</td></tr><tr><td>Tropical</td><td><2000</td><td>1000–1600</td><td>1</td></tr><tr><td>Tropical</td><td><2000</td><td>>1600</td><td>1</td></tr><tr><td>Tropical</td><td>>2000</td><td>All</td><td>1</td></tr><tr><td>Temperate/boreal</td><td>All</td><td>All</td><td>4</td></tr></table> |
| Purpose of data | Calculation of project emissions |
| Comments | N/A |

| | |
|---|---|
| Data / Parameter | $C_{WP_{SOC,REF}}$ |
| Data unit | t C ha$^{-1}$ |
| Description | Reference SOC stock corresponding to the reference condition in native lands (i.e., non-degraded, unimproved lands under native vegetation — normally forest) by climate region and soil type applicable to the project area |
| Equations | (26), (28) |
| Source of data | Taken from the CDM *A/R Methodological Tool – Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities*,[23] referencing IPCC values |

[23] Clean Development Mechanism (2011). *AR-TOOL16: A/R Methodological Tool – Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities*, *v.01.1.0*. https://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-16-v1.1.0.pdf/history_view

<table>
<tr><td>Value applied</td><td>Table 3: Default reference SOC stocks ($SOC_{REF}$) for mineral soils[3]<br>($tC\ ha^{-1}$ in 0-30 cm depth)
<table>
<tr><th>Climate region</th><th>HAC soils[(a)]</th><th>LAC soils[(b)]</th><th>Sandy soils[(c)]</th><th>Spodic soils[(d)]</th><th>Volcanic soils[(e)]</th></tr>
<tr><td>Boreal</td><td>68</td><td>NA</td><td>10</td><td>117</td><td>20</td></tr>
<tr><td>Cold temperate, dry</td><td>50</td><td>33</td><td>34</td><td>NA</td><td>20</td></tr>
<tr><td>Cold temperate, moist</td><td>95</td><td>85</td><td>71</td><td>115</td><td>130</td></tr>
<tr><td>Warm temperate, dry</td><td>38</td><td>24</td><td>19</td><td>NA</td><td>70</td></tr>
<tr><td>Warm temperate,</td><td>88</td><td>63</td><td>34</td><td>NA</td><td>80</td></tr>
<tr><td>Tropical, dry</td><td>38</td><td>35</td><td>31</td><td>NA</td><td>50</td></tr>
<tr><td>Tropical, moist</td><td>65</td><td>47</td><td>39</td><td>NA</td><td>70</td></tr>
<tr><td>Tropical, wet</td><td>44</td><td>60</td><td>66</td><td>NA</td><td>130</td></tr>
<tr><td>Tropical montane</td><td>88</td><td>63</td><td>34</td><td>NA</td><td>80</td></tr>
</table>
(a) Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols);<br>
(b) Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols);<br>
(c) Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols; in USDA classification includes Psamments);<br>
(d) Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols);<br>
(e) Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)</td></tr>
<tr><td>Justification of choice of data or description of measurement methods and procedures applied</td><td>IPCC is a reputable source approved by the VCS.</td></tr>
<tr><td>Purpose of Data</td><td>Calculation of project emissions</td></tr>
<tr><td>Comments</td><td></td></tr>
</table>

| Data / Parameter | $f_{LU}$ |
|---|---|
| Data unit | Dimensionless |
| Description | Stock change factor for land use |
| Equations | (28) |
| Source of data | Taken from the CDM *A/R Methodological Tool – Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities*,[24] referencing IPCC values. |

[24] Ibid.

| | |
|---|---|
| Value applied | Table 4: Relative stock change factors for different management activities on cropland (net effect over a period of 20 years)[4] |

| Factor type | Level | Temperature regime | Moisture regime | Factor value | Description and criteria |
|---|---|---|---|---|---|
| Land use ($f_{LU}$) | Long-term cultivated | Temperate/ Boreal | Dry | 0.80 | Area has been continuously managed for crops for more than 20 years |
| | | | Moist | 0.69 | |
| | | Tropical | Dry | 0.58 | |
| | | | Moist/Wet | 0.48 | |
| | | Tropical montane | n/a | 0.64 | |
| Land use ($f_{LU}$) | Short-term cultivated (< 20 yrs) or set aside (< 5 years) | Temperate/ Boreal and Tropical | Dry | 0.93 | Area has been managed for crops for less than 20 years and/or the area is cropland that has been in a fallow state for less than five years at any point during the last 20 years |
| | | | Moist/Wet | 0.82 | |
| | | Tropical montane | n/a | 0.88 | |
| Manage-ment ($f_{MG}$) | Full tillage | All | Dry and Moist/Wet | 1.00 | Substantial soil disturbance with full inversion and/or frequent (within-year) tillage operations. At planting time, little (e.g. <30%) of the surface is covered by residues |
| Manage-ment ($f_{MG}$) | Reduced tillage | Temperate/ Boreal | Dry | 1.02 | Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally leaves surface with >30% coverage by residues at planting |
| | | | Moist | 1.08 | |
| | | Tropical | Dry | 1.09 | |
| | | | Moist/ Wet | 1.15 | |
| | | Tropical montane | n/a | 1.09 | |

| | |
|---|---|
| Justification of choice of data or description of measurement methods and procedures applied | IPCC is a reputable source approved by the VCS. |
| Purpose of Data | Calculation of project emissions |
| Comments | |

| | |
|---|---|
| Data / Parameter | $f_{MG}$ |
| Data unit | Dimensionless |
| Description | Stock change factor for management regime |
| Equations | (28) |
| Source of data | Taken from the CDM *A/R Methodological Tool – Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities*,[25] referencing IPCC values |

[25] Ibid.

| | |
|---|---|
| Value applied | **Table 4: Relative stock change factors for different management activities on cropland (net effect over a period of 20 years)** [4] |

| Factor type | Level | Temperature regime | Moisture regime | Factor value | Description and criteria |
|---|---|---|---|---|---|
| Land use ($f_{LU}$) | Long-term cultivated | Temperate/ Boreal | Dry | 0.80 | Area has been continuously managed for crops for more than 20 years |
| | | | Moist | 0.69 | |
| | | Tropical | Dry | 0.58 | |
| | | | Moist/Wet | 0.48 | |
| | | Tropical montane | n/a | 0.64 | |
| Land use ($f_{LU}$) | Short-term cultivated (< 20 yrs) or set aside (< 5 years) | Temperate/ Boreal and Tropical | Dry | 0.93 | Area has been managed for crops for less than 20 years and/or the area is cropland that has been in a fallow state for less than five years at any point during the last 20 years |
| | | | Moist/Wet | 0.82 | |
| | | Tropical montane | n/a | 0.88 | |
| Manage-ment ($f_{MG}$) | Full tillage | All | Dry and Moist/Wet | 1.00 | Substantial soil disturbance with full inversion and/or frequent (within-year) tillage operations. At planting time, little (e.g. <30%) of the surface is covered by residues |
| Manage-ment ($f_{MG}$) | Reduced tillage | Temperate/ Boreal | Dry | 1.02 | Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally leaves surface with >30% coverage by residues at planting |
| | | | Moist | 1.08 | |
| | | Tropical | Dry | 1.09 | |
| | | | Moist/ Wet | 1.15 | |
| | | Tropical montane | n/a | 1.09 | |

| | |
|---|---|
| Justification of choice of data or description of measurement methods and procedures applied | IPCC is a reputable source approved by the VCS. |
| Purpose of Data | Calculation of project emissions |
| Comments | |

| | |
|---|---|
| Data / Parameter | $f_{IN}$ |
| Data unit | Dimensionless |
| Description | Stock change factor for input of organic matter |
| Equations | (28) |
| Source of data | Taken from the CDM *A/R Methodological Tool – Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities*,[26] referencing IPCC values |

[26] Ibid.

<table>
<tr><td>Value applied</td><td>
Table 5: Relative stock change factors for different levels of nutrient input on cropland (net effect over a period of 20 years)[5]
<table>
<tr><th>Factor type</th><th>Level</th><th>Temperature regime</th><th>Moisture regime</th><th>Factor value</th><th>Description and criteria</th></tr>
<tr><td rowspan="5">Input ($f_{IN}$)</td><td rowspan="5">Low</td><td rowspan="2">Temperate/ Boreal</td><td>Dry</td><td>0.95</td><td rowspan="5">There is removal of residues (via collection or burning), or frequent bare-fallowing, or production of crops yielding low residues (e.g. vegetables, tobacco, cotton), or no mineral fertilization or N-fixing crops</td></tr>
<tr><td>Moist</td><td>0.92</td></tr>
<tr><td rowspan="2">Tropical</td><td>Dry</td><td>0.95</td></tr>
<tr><td>Moist/ Wet</td><td>0.92</td></tr>
<tr><td>Tropical montane</td><td>n/a</td><td>0.94</td></tr>
<tr><td>Input ($f_{IN}$)</td><td>Medium</td><td>All</td><td>Dry and Moist/ Wet</td><td>1.00</td><td>All crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g. manure) is added. Additionally, mineral fertilization or N-fixing crop rotation is practised</td></tr>
<tr><td rowspan="3">Input ($f_{IN}$)</td><td rowspan="3">High with-out manure</td><td rowspan="2">Temperate/ Boreal and Tropical</td><td>Dry</td><td>1.04</td><td rowspan="3">Represents significantly greater crop residue inputs over medium C input cropping systems due to additional practices, such as production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, irrigation, frequent use of perennial grasses in annual crop rotations, but without manure applied</td></tr>
<tr><td>Moist/ Wet</td><td>1.11</td></tr>
<tr><td>Tropical Montane</td><td>n/a</td><td>1.08</td></tr>
</table>
</td></tr>
<tr><td>Justification of choice of data or description of measurement methods and procedures applied</td><td>IPCC is a reputable source approved by the VCS.</td></tr>
<tr><td>Purpose of Data</td><td>Calculation of project emissions</td></tr>
<tr><td>Comments</td><td></td></tr>
</table>

| Data / Parameter | $COMF$ |
|---|---|
| Data unit | Dimensionless |
| Description | Combustion factor |
| Equations | (30), (32) |
| Source of data | Default values from the *2006 IPCC Guidelines for National Greenhouse Inventories*[27] |
| Value applied | The combustion factor is selected based on vegetation type. |
| Justification of choice of data or description of | See source of data above |

[27] Table 2.6, Chapter 2, Volume 4 in Intergovernmental Panel on Climate Change (2006). *IPCC Guidelines for National Greenhouse Gas Inventories*, IGES. https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

| | |
|---|---|
| measurement methods and procedures applied | |
| Purpose of data | Calculation of project emissions |
| Comments | N/A |

| | |
|---|---|
| Data / Parameter | $EF_g$ |
| Data unit | kg $t^{-1}$ dry matter burnt |
| Description | Emission factor for gas $g$ |
| Equations | (30), (32) |
| Source of data | Based on default values from the *IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry*[28] |
| Value applied | The emission factor is selected based on the forest type. |
| Justification of choice of data or description of measurement methods and procedures applied | See source of data above |
| Purpose of data | Calculation of project emissions |
| Comments | N/A |

| | |
|---|---|
| Data / Parameter | $GWP_g$ |
| Data unit | Dimensionless |
| Description | Global warming potential for gas $g$ |
| Equations | (30), (32) |
| Source of data | Default factor from the latest IPCC Assessment Report |
| Value applied | N/A |

[28] Table 3A.1.16 in Intergovernmental Panel on Climate Change (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry*, IGES. https://www.ipcc.ch/publication/good-practice-guidance-for-land-use-land-use-change-and-forestry/

| | |
|---|---|
| Justification of choice of data or description of measurement methods and procedures applied | N/A |
| Purpose of data | Calculation of project emissions |
| Comments | N/A |

| | |
|---|---|
| Data / Parameter | $NC_{WP,SF,i,t}$ |
| Data unit | t N t fertilizer$^{-1}$ |
| Description | N content of synthetic fertilizer applied in the project scenario |
| Equations | (35) |
| Source of data | N content is determined following fertilizer manufacturer's specifications. |
| Value applied | |
| Justification of choice of data or description of measurement methods and procedures applied | |
| Purpose of data | Calculation of project emissions |
| Comments | None |

| | |
|---|---|
| Data / Parameter | $NC_{WP,OF,i,t}$ |
| Data unit | t N t fertilizer$^{-1}$ |
| Description | N content of organic fertilizer applied in the project scenario |
| Equations | (35) |
| Source of data | Peer-reviewed published data may be used. For example, default manure N content may be selected from Edmonds et al. (2003)[29] |

[29] Edmonds, L., Gollehon, N., Kellogg, R. L., Kintzer, B., Knight, L., Lander, C., Lemunyon, J., Meyer, D., Moffitt, D. C., & Schaeffer, J. (2003). *Costs Associated with Development and Implementation of Comprehensive Nutrient Management Plans. Part 1. Nutrient Management, Land Treatment, Manure and Wastewater Handling and Storage, and Recordkeeping*. Natural Resource Conservation Service, U.S. Department of Agriculture.

| | |
|---|---|
| | cited in U.S. EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009.*[30] |
| Value applied | |
| Justification of choice of data or description of measurement methods and procedures applied | See source of data above |
| Purpose of data | Calculation of project emissions |
| Comments | None |

## 9.2 Data and Parameters Monitored

| Data / Parameter | $LA$ |
|---|---|
| Data unit | t $CO_2e$ |
| Description | Long-term average GHG benefit in the project scenario with harvesting in time period $n$ |
| Equations | (41) |
| Source of data | Refer to monitoring data for net emission reductions (NGRs) |
| Description of measurement methods and procedures to be applied | |
| Frequency of monitoring/recording | Each monitoring period |
| QA/QC procedures to be applied | See Section 9.3 |
| Purpose of data | Calculation of maximum GHG benefits |
| Calculation method | See Equation (41) |

[30] U.S. Environmental Protection Agency (2011). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009. EPA 430-R-11-005*. Washington, D.C. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2009

| | |
|---|---|
| Comments | |

| | |
|---|---|
| Data / Parameter | $M_t$ |
| Data unit | % |
| Description | Cumulative mortality in year $t$ |
| Equations | (10) |
| Source of data | Complete re-enumeration, or sampling |
| Description of measurement methods and procedures to be applied | If sampling, planting units must be representatively sampled from the census list on which parameter $N$ is based, compiled prior to sampling. Stratification (e.g., sub-dividing the census list into annual cohorts) may be employed to improve precision but is not required. An appropriate representative sample would be a stratified systematic sample, within each annual cohort, selecting planting units systematically with a random start from the list of unique censused planting units.<br><br>Planting units are assessed as dead if:<br>1) Green vascular tissue (e.g., cambium of trees and shrubs) and green leaves are absent; or<br>2) The planting unit cannot be re-located. |
| Frequency of monitoring/recording | Every 5 years or less frequently during the project. Sampling for incidence of mortality can be conducted simultaneously with sampling planting units for biomass measurement. |
| QA/QC procedures to be applied | |
| Purpose of data | Calculation of project emissions |
| Calculation method | |
| Comments | Planting units must be clearly defined (e.g., tree, shrub, bamboo clump) and identifiable in the field. |

| | |
|---|---|
| Data / Parameter | $C_{WP_{woody_{AB,t}}}$ |

| | |
|---|---|
| Data unit | t $CO_2e$ per hectare (area-based quantification) or<br><br>t $CO_2e$ per planting unit (census-based quantification) |
| Description | Live aboveground biomass stocks in the project scenario in year *t* |
| Equations | (8), (11), (23), (31) |
| Source of data | Measured in project area |
| Description of measurement methods and procedures to be applied | With area-based quantification, live aboveground biomass will be measured via plot-based sampling.<br><br>With census-based quantification, live aboveground biomass will be measured via sampling from a complete census of planting units.<br><br>Acknowledging the wide range of valid approaches, and that relative efficiency and robustness are circumstance-specific, sampling, measurement, and estimation procedures are not specified in the methodology and may be selected by project proponents based on capacity and appropriateness. Stratification may be employed to improve precision but is not required.<br><br>Plot-based sampling approaches (using area-based quantification) may be augmented using double or two-phase sampling approaches combining limited direct plot-based field measurements with wall-to-wall remote sensing metrics to eliminate sample error (and replace with model error). Any remote sensing metrics employed must have demonstrated correlations with biomass (e.g., the Normalized Degradation Fraction Index[31] from Landsat imagery, or average canopy height derived from Lidar). The remote sensing metric applied must satisfy the following:<br><br>1) Significant correlation with aboveground biomass pools included in the project boundary, previously substantiated with published studies<br>2) Validated with direct measurements of aboveground biomass pools included in the project boundary from the project region (within the national boundary), demonstrating a statistically significant ($p < 0.05$) relationship |

[31] Souza Jr, C. M., Roberts, D. A., & Cochrane, M. A. (2005). Combining spectral and spatial information to map canopy damage from selective logging and forest fires. *Remote Sensing of Environment*, *98*(2–3), 329–343. https://doi.org/10.1016/j.rse.2005.07.013

| | |
|---|---|
| | 3) Model (ratio or regression) error quantified and assessed in parameter $U_{p,t}$ where $p$ = woody<br><br>All sample measurements must:<br><br>1) Be demonstrated to be unbiased and derived from representative sampling;<br>2) Have their accuracy ensured through adherence to best practices and quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection); and<br>3) Apply fixed diameter at breast height (dbh) and any other size thresholds.<br><br>Aboveground biomass of each sampled tree will be estimated using published allometric equations (species-, genus- or family-specific, in descending order of preference, as available) applied to one or more measured tree attributes. Where using component ratio methods, stem volumes must be estimated by applying published volume equations.<br><br>Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly measured in the field, applying established best practices such as those found in:<br><br>Kershaw Jr, J. A., Ducey, M. J., Beers, T. W., & Husch, B. (2016). *Forest Mensuration*. Fifth edition. John Wiley & Sons.<br><br>Avery, T. E. & Burkhart, H. E. (2015). *Forest Measurements*. Fifth edition. Waveland Press.<br><br>Measurement protocols will be detailed in standard operating procedures. Parameter tables for all tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be included in the project description under Data and Parameters Monitored. |
| Frequency of monitoring/recording | Every 5 years or less frequently in the project |
| QA/QC procedures to be applied | |
| Purpose of data | Calculation of project emissions |

| | |
|---|---|
| Calculation method | |
| Comments | *VT0005 Tool for measuring aboveground live forest biomass using remote sensing, v1.0* does not apply. |

| | |
|---|---|
| Data / Parameter | $V_{ex,ty,j,t}$ |
| Data unit | m³ |
| Description | The volume of commercial timber extracted from within the project area in the monitoring interval ending in year $t$, reported by wood product class $ty$ and species $j$. |
| Equations | (15) |
| Source of data | Field measurements or mill receipts |
| Description of measurement methods and procedures to be applied | **Area-based quantification**<br><br>Volume of commercial timber extracted is sourced from scaled volumes verified from mill or hauling receipts dated to the monitoring interval ending in year $t$, accompanied by records that identify the source area of the received wood.<br><br>**Census-based quantification**<br><br>Volume of commercial timber extracted is calculated from field measurements of sampled planting units (described further in Section 8.2.2) conducted prior to harvest, as:<br><br>$$V_{ex,ty,j,t} = N_i \times \frac{n_{ex,i,t}}{n_{i,t}} \times V_{i,ty,j,t-x}$$<br><br>Where:<br><br>$V_{ex,ty,j,t}$ = Volume of commercial timber extracted from the project area (does not include slash left onsite), by species $j$ and wood product class $ty$ in the monitoring interval ending in year $t$ (m³)<br><br>$V_{i,ty,j,t-x}$ = Average bole/stem volume assessed for sampled planting units in cohort $i$ in the monitoring interval ending in year $t-x$ (prior to extraction), by species $j$ and wood product class $ty$ (m³)<br><br>$N_i$ = Initial population size in cohort $i$ (number of planting units) |

| | |
|---|---|
| | $n_{i,t}$ Number of planting units sampled in cohort $i$ in year $t$ (number)<br><br>$n_{ex,i,t}$ Number of sampled planting units in cohort $i$ extracted in the monitoring interval ending in year $t$ (number)<br><br>$t$ Time elapsed (1, 2, 3, …, $T$) since the project start date (y)<br><br>For parameter $n_{ex,i,t}$, sampled planting units recorded as extracted must:<br><br>1) Have been visibly cut at or near the stem base;<br>2) Be of a commercial wood species; and<br>3) Have a written attestation from a project participant that they were cut and delivered to a commercial timber buyer during the monitoring interval ending in year $t$.<br><br>Bole/stem volume is estimated by applying published volume equations. Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly measured in the field, applying established best practices such as those found in:<br><br>Kershaw Jr, J. A., Ducey, M. J., Beers, T. W., & Husch, B. (2016). *Forest Mensuration*. Fifth edition. John Wiley & Sons.<br><br>Avery, T. E. & Burkhart, H. E. (2015). *Forest Measurements*. Fifth edition. Waveland Press.<br><br>Measurement protocols will be detailed in standard operating procedures. Parameter tables for all tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be included in the project description under Data and Parameters Monitored. |
| Frequency of monitoring/recording | Every 5 years or less frequently |
| QA/QC procedures to be applied | |
| Purpose of data | |
| Calculation method | |
| Comments | This parameter is restricted to commercial timber species. |

| | |
|---|---|
| | Note that this volume does not include logging slash left onsite. Assignment of volume extracted to wood product class(es) must be substantiated on the basis of records of timber sales or consultation with local land managers and/or processing facilities receiving harvested volumes from the project area. |

| Data / Parameter: | $C_{WP_{SDW_{pu,i,t}}}$ |
|---|---|
| Data unit: | t dry matter pu$^{-1}$ |
| Description: | Average carbon stock in standing dead wood per planting unit ($pu$) observed as standing dead in cohort $i$ in the project scenario in year $t$ |
| Equations | (20) |
| Source of data: | Field measurements |
| Description of measurement methods and procedures to be applied: | With census-based quantification, standing dead wood will be measured via representative sampling from a complete census of planting units. Stratification (e.g., sub-dividing the census list into annual cohorts) may be employed to improve precision but is not required. An appropriate representative sample would be a stratified systematic sample, within each annual cohort, selecting planting units systematically with a random start from the list of unique censused planting units.<br><br>Sample measurements must:<br><br>1) Be demonstrated to be unbiased and derived from representative sampling;<br>2) Have their accuracy ensured through adherence to best practices and QA/QC procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection); and<br>3) Apply fixed size thresholds.<br><br>For each standing dead tree, stem volume must be estimated using published volume equations (species-, genus- or family-specific, in descending order of preference, as available), applied to one or more measured tree attributes, minimally including dbh and remaining stem height. Note that standing dead wood is restricted here to aboveground stem (bole) biomass.<br><br>Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly |

| | |
|---|---|
| | measured in the field, applying established best practices such as those found in:<br><br>Kershaw Jr, J. A., Ducey, M. J., Beers, T. W., & Husch, B. (2016). *Forest Mensuration*. Fifth edition. John Wiley & Sons.<br><br>Avery, T. E., & Burkhart, H. E. (2015). *Forest Measurements*. Fifth edition. Waveland Press.<br><br>Measurement protocols will be detailed in standard operating procedures. Parameter tables for all tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be included in the project description under Data and Parameters Monitored.<br><br>Biomass of standing dead wood must be estimated from sampled volumes using published wood densities (species-, genus- or family-specific, in descending order of preference, as available) and density reduction factors referencing decomposition states (e.g., procedures per Harmon et al., 2011[32]). |
| Frequency | Every 5 years or less frequently |
| QA/QC procedures to be applied: | |
| Purpose of data: | Calculation of project emissions |
| Calculation method: | |
| Comments: | |

| | |
|---|---|
| Data / Parameter: | $C_{WP_{burn}{}_{pu,i,t-\Delta t}}$ |
| Data unit: | t dry matter pu$^{-1}$ |
| Description: | Average dry mass per planting unit ($pu$) observed as burned in cohort $i$ in the project scenario in year $t$, measured in year $t-\Delta t$ |
| Equations | (33) |
| Source of data: | Field measurements |

[32] Harmon, M. E., Woodall, C. W., Fasth, B., Sexton, J., & Yatkov, M. (2011). Differences between standing and downed dead tree wood density reduction factors: A comparison across decay classes and tree species. Research Paper NRS-15. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station. https://doi.org/10.2737/NRS-RP-15

| | |
|---|---|
| Description of measurement methods and procedures to be applied: | With census-based quantification, planting units will be measured via representative sampling from a complete census of planting units. Stratification (e.g., sub-dividing the census list into annual cohorts) may be employed to improve precision but is not required. An appropriate representative sample would be a stratified systematic sample, within each annual cohort, selecting planting units systematically with a random start from the list of unique censused planting units.<br><br>Sample measurements must:<br><br>1) Be demonstrated to be unbiased and derived from representative sampling;<br>2) Have their accuracy ensured through adherence to best practices and QA/QC procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection); and<br>3) Apply fixed size thresholds.<br><br>For each visibly burned and killed planting unit, stem volume must be estimated using published biomass equations (species-, genus- or family-specific, in descending order of preference, as available), applied to one or more tree attributes measured prior to the burn (at time $t - \Delta t$). Note that this parameter is restricted here to aboveground biomass.<br><br>Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly measured in the field, applying established best practices such as those found in:<br><br>Kershaw Jr, J. A., Ducey, M. J., Beers, T. W., & Husch, B. (2016). *Forest Mensuration*. Fifth edition. John Wiley & Sons.<br><br>Avery, T. E. & Burkhart, H. E. (2015). *Forest Measurements*. Fifth edition. Waveland Press.<br><br>Measurement protocols will be detailed in standard operating procedures. Parameter tables for all tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be included in the project description under Data and Parameters Monitored. |
| Frequency | Every 5 years or less frequently |

| | |
|---|---|
| QA/QC procedures to be applied: | |
| Purpose of data: | Calculation of project emissions |
| Calculation method: | |
| Comments: | |

| Data / Parameter | $U_{p,t}$ |
|---|---|
| Data unit | % |
| Description | Percentage uncertainty (expressed as 95% confidence interval, as a percentage of the mean) in carbon stock estimate of pool $p$ in the project scenario in year $t$ |
| Equations | (37), (38) |
| Source of data | Calculations from sampled field measurements |
| Description of measurement methods and procedures to be applied | Uncertainty in pools derived from field measurements with 95% confidence interval, calculated as the standard error of the averaged plot measurements in each stratum multiplied by the $t$ value for the 95% confidence level.<br><br>Where double or two-phase sampling approaches are used with a wall-to-wall remote sensing metric, parameter $U_{\text{woody},t}$ is represented by model error in the relationship (ratio or regression) between the remote sensing metric and aboveground biomass, referencing the 95% confidence interval of the ratio or twice the root mean squared error of the regression. |
| Frequency of monitoring/recording | Every 5 years or less frequently |
| QA/QC procedures to be applied | |
| Purpose of data | Calculation of uncertainty |
| Calculation method | |
| Comments | For the area-based quantification approach, pools $p$ include woody biomass, herbaceous biomass, dead wood, harvested wood |

| | |
|---|---|
| | products, litter, and SOC. Where conservative default values of SOC are applied, parameter $U_{\mathrm{SOC},t}$ is assumed to equal zero. For harvested wood products, $U_{\mathrm{HWP},t}$ is assumed to equal zero (as it is not sample-based, but derived from scaled volumes from verified mill or hauling receipts).<br>For the census-based quantification approach, pools $p$ include woody biomass, dead wood, and harvested wood products. For harvested wood products, $U_{\mathrm{HWP},t}$ is assumed to be equal to that for woody biomass. |

| Data / Parameter | $A_{burn,t}$ |
|---|---|
| Data unit | ha |
| Description | Area burnt at time $t$ |
| Equations | (30) |
| Source of data | Calculated from GIS data |
| Description of measurement methods and procedures to be applied | Delineation of the area burned may use a combination of remote imagery (satellite or aerial photographs) or ground survey data with GPS. |
| Frequency of monitoring/recording | Every 5 years or less frequently |
| QA/QC procedures to be applied | Any imagery used must be geo-registered by referencing corner points, clear landmarks, or other intersection points. |
| Purpose of data | Calculation of project emissions |
| Calculation method | |
| Comments | |

| Data / Parameter | $A_{fert,t}$ |
|---|---|
| Data unit | ha |
| Description | Area in which nitrogen fertilizer is applied in year $t$ |

| | |
|---|---|
| Equations | (34) |
| Source of data | Management records specifying area(s) of fertilizer application |
| Description of measurement methods and procedures to be applied | Referencing management records, the spatial boundary within which nitrogen fertilizer has been applied must be delineated in GIS and the area calculated. |
| Frequency of monitoring/recording | Every 5 years or less frequently |
| QA/QC procedures to be applied | |
| Purpose of data | Calculation of project emissions |
| Calculation method | |
| Comments | |

| | |
|---|---|
| Data / Parameter: | $M_{WP,SF,i,t}$ |
| Data unit: | t fertilizer |
| Description: | Mass of N-containing synthetic fertilizer applied in $A_{fert}$ in the monitoring interval ending in year $t$ |
| Equations | (35) |
| Source of data: | |
| Description of measurement methods and procedures to be applied: | |
| Frequency of monitoring/recording: | Monitoring must be conducted at least once every five years, or prior to each verification event where these are more frequent than once every five years. |
| QA/QC procedures to be applied: | Information will be monitored via direct consultation with, and substantiated by a written attestation from, the local land manager. Any quantitative information (e.g., discrete or continuous |

| | |
|---|---|
| | numeric variables) on management practices must be supported by one or more forms of documented evidence pertaining to the project area and relevant monitoring period (e.g., management logs, receipts, or invoices). |
| Purpose of data: | Calculation of project emissions |
| Calculation method: | N/A |
| Comments: | |

| Data / Parameter: | $M_{WP,OF,i,t}$ |
|---|---|
| Data unit: | t fertilizer |
| Description: | Mass of N-containing organic fertilizer applied in $A_{fert}$ in the monitoring interval ending in year $t$ |
| Equations | (35) |
| Source of data: | |
| Description of measurement methods and procedures to be applied: | |
| Frequency of monitoring/recording: | Monitoring must be conducted at least once every five years, or prior to each verification event where these are more frequent than once every five years. |
| QA/QC procedures to be applied: | Information will be monitored via direct consultation with, and substantiated by a written attestation from, a local land manager. Any quantitative information (e.g., discrete or continuous numeric variables) on management practices must be supported by one or more forms of documented evidence pertaining to the project area and relevant monitoring period (e.g., management logs, receipts, or invoices). |
| Purpose of data: | Calculation of project emissions |
| Calculation method: | N/A |
| Comments: | |

| Data / Parameter: | $B_{SDW,t}$ |
|---|---|
| Data unit: | t dry matter ha$^{-1}$ |
| Description: | Biomass of standing dead wood in year $t$ |
| Equations | (18) |
| Source of data: | Field measurements |
| Description of measurement methods and procedures to be applied: | Standing dead wood will be sampled via plot-based forest inventory methods. Specific sample designs/intensities, measurements, and estimation procedures may be selected by project proponents based on capacity and appropriateness. Stratification may be employed to improve precision but is not required.<br><br>Sample measurements must:<br>1) Be demonstrated to be unbiased and derived from representative sampling;<br>2) Have their accuracy ensured through adherence to best practices and QA/QC procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection); and<br>3) Apply fixed size thresholds.<br><br>For each standing dead tree, stem volume must be estimated using published volume equations (species-, genus- or family-specific, in descending order of preference, as available), applied to one or more measured tree attributes, minimally including dbh and remaining stem height. Note that standing dead wood is restricted here to aboveground stem (bole) biomass.<br><br>Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly measured in the field, applying established best practices such as those found in:<br><br>Kershaw Jr, J. A., Ducey, M. J., Beers, T. W., & Husch, B. (2016). *Forest Mensuration*. Fifth edition. John Wiley & Sons.<br><br>Avery, T. E., & Burkhart, H. E. (2015). *Forest Measurements*. Fifth edition. Waveland Press. |

| | |
|---|---|
| | Measurement protocols will be detailed in standard operating procedures. Parameter tables for all tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be included in the project description under Data and Parameters Monitored.<br><br>Biomass of standing dead wood must be estimated from sampled volumes using published wood densities (species-, genus- or family-specific, in descending order of preference, as available) and density reduction factors referencing decomposition states (e.g., procedures per Harmon et al., 2011[33]). |
| Frequency | Every 5 years or less frequently |
| QA/QC procedures to be applied: | |
| Purpose of data: | Calculation of project emissions |
| Calculation method: | |
| Comments: | |

| Data / Parameter: | $B_{LDW,t}$ |
|---|---|
| Data unit: | t dry matter ha$^{-1}$ |
| Description: | Biomass of lying dead wood in year $t$ |
| Equations | (18) |
| Source of data: | Field measurements |
| Description of measurement methods | Lying dead wood will be sampled via line intersect sampling,[34] perpendicular distance sampling,[35] or other un-biased |

[33] Harmon, M. E., Woodall, C. W., Fasth, B., Sexton, J., & Yatkov, M. (2011). Differences between standing and downed dead tree wood density reduction factors: A comparison across decay classes and tree species. Research Paper NRS-15. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station. https://doi.org/10.2737/NRS-RP-15

[34] Warren, W. G., & Olsen, P. F. (1964). A line intersect technique for assessing logging waste. *Forest Science*, *10*(3), 267–276. https://doi.org/10.1093/forestscience/10.3.267
Van Wagner, C. E. (1968). The line intersect method in forest fuel sampling. *Forest Science*, *14*(1), 20–26. https://doi.org/10.1093/forestscience/14.1.20

[35] Williams, M. S., & Gove, J. H. (2003). Perpendicular distance sampling: An alternative method for sampling downed coarse woody debris. *Canadian Journal of Forest Research*, *33*(8), 1564–1579. https://doi.org/10.1139/x03-056

| | |
|---|---|
| and procedures to be applied: | approaches. Specific sample designs/intensities, measurements, and estimation procedures may be selected by project proponents based on capacity and appropriateness. Stratification may be employed to improve precision but is not required.<br><br>Sample measurements must:<br><br>1) Be demonstrated to be unbiased and derived from representative sampling;<br>2) Have their accuracy ensured through adherence to best practices and QA/QC procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection); and<br>3) Apply fixed size thresholds.<br><br>Protocols will be detailed in standard operating procedures and parameter tables under Data and Parameters Monitored for all lying dead wood attributes (e.g., cross-sectional diameter, length) measured and recorded.<br><br>Biomass of lying dead wood must be estimated from sampled volumes using published wood densities (species-, genus- or family-specific, in descending order of preference, as available) and density reduction factors referencing decomposition states (e.g., procedures per Harmon et al., 2011[36]). |
| Frequency | Every 5 years or less frequently |
| QA/QC procedures to be applied: | |
| Purpose of data: | Calculation of project emissions |
| Calculation method: | |
| Comments: | |

Williams, M. S., Valentine, H. T., Gove, J. H., & Ducey, M. J. (2005). Additional results for perpendicular distance sampling. *Canadian Journal of Forest Research*, *35*(4), 961–966. https://doi.org/10.1139/x05-023
Ducey, M. J., Williams, M. S., Gove, J. H., Roberge, S., & Kenning, R. S. (2013). Distance-limited perpendicular distance sampling for coarse woody debris: Theory and field results. *Forestry*, *86*(1), 119–128. https://doi.org/10.1093/forestry/cps059

[36] Harmon, M. E., Woodall, C. W., Fasth, B., Sexton, J., & Yatkov, M. (2011). Differences between standing and downed dead tree wood density reduction factors: A comparison across decay classes and tree species. Research Paper NRS-15. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station. https://doi.org/10.2737/NRS-RP-15

| | |
|---|---|
| Data / Parameter: | $DM_{WP_{LI,t}}$ |
| Data unit: | t dry matter ha$^{-1}$ |
| Description: | Litter dry mass in the project scenario in year $t$ |
| Equations | (22) |
| Source of data: | Measured in the project area |
| Description of measurement methods and procedures to be applied: | Litter (dead organic surface material of <10 cm diameter) is collected from within fixed-area sampling frames, harvested at ground level and dried at 70 °C to a constant weight to determine dry weight biomass. In cases where sample bulk is excessive, the green weight of the total sample and of a representative sub-sample are recorded in the field and the sub-sample taken for moisture content determination in the lab (i.e., oven dry weight to green weight ratio), from which the dry weight biomass of the total green weight recorded in the field can be estimated.<br><br>Further guidance is provided in the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry*.[37] |
| Frequency of monitoring/recording: | At $t = 0$ and subsequently every 10 years or less frequently |
| QA/QC procedures to be applied: | Standard QA/QC procedures for soil inventory, including field data collection and data management, must be applied. Use or adaptation of QA/QC procedures available from published handbooks, such as those published by FAO and available on the FAO Soils Portal[38] or from the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* is recommended. |
| Purpose of data: | Calculation of project emissions |
| Calculation method: | N/A |
| Comments: | N/A |

| | |
|---|---|
| Data / Parameter: | $C_{WP_{SOC,t}}$ |

[37] Intergovernmental Panel on Climate Change (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry*, IGES. https://www.ipcc.ch/publication/good-practice-guidance-for-land-use-land-use-change-and-forestry/
[38] Available at http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/

| | |
|---|---|
| Data unit: | t C ha$^{-1}$ |
| Description: | Soil organic carbon stock in year *t* |
| Equations | (29) |
| Source of data: | Measured in the project area |
| Description of measurement methods and procedures to be applied: | Measured soil organic carbon must be determined from samples collected from sample plots located within the project area. All organic material (e.g., living plants, litter) must be cleared from the soil surface prior to soil sampling. Soil must be sampled to a minimum depth of 30 cm. Soil organic carbon stocks must be estimated from measurements of both soil organic carbon content and bulk density taken at the same time.<br><br>Acknowledging the wide range of valid monitoring approaches, and that relative efficiency and robustness are circumstance-specific, sampling, measurement, and estimation procedures are not specified in the methodology and may be selected by project proponents based on capacity and appropriateness. Stratification may be employed to improve precision but is not required. Estimates generated must:<br><br>1) Be demonstrated to be unbiased and derived from representative sampling; and<br>2) Have their accuracy ensured through adherence to QA/QC procedures (to be determined by the project proponent and outlined in the monitoring plan).<br><br>Soil sampling should follow established best practices, such as those found in:<br><br>Cline, M. G. (1944). Principles of soil sampling. *Soil Science*. *58*(4), 275–288.<br><br>Petersen, R. G., & Calvin, L. D. (1986). Sampling. In A. Klute (Ed.) 1986. *Methods of Soil Analysis: Part 1—Physical and Mineralogical Methods* (pp. 33–51). SSSA Book Ser. 5.1. SSSA, ASA, Madison, WI.<br><br>Determination of percentage soil organic carbon should follow established laboratory procedures, such as those found in:<br><br>Nelson, D. W., & Sommers, L. E. (1982). Total carbon, organic carbon, and organic matter. In A. L. Page (Ed.) *Methods of Soil* |

| | |
|---|---|
| | *Analysis: Part 2 Chemical and Microbiological Properties* Second edition (pp. 539–580). Agronomy Monographs. ASA and SSSA, Madison, WI.<br><br>Schumacher, B. A. (2002). *Methods for the determination of total organic carbon (TOC) in soils and sediments.* U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-02/069 (NTIS PB2003-100822) or other regionally appropriate sources such as the European Environment Agency.<br><br>Procedures for soil organic carbon and bulk density (including all sample handling, preparation for analysis, and analysis techniques) will be thoroughly described in field sampling protocols and in parameter tables under Data and Parameters Monitored. |
| Frequency of monitoring/recording: | At $t = 0$ and subsequently every 10 years or less frequently |
| QA/QC procedures to be applied: | Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QC procedures available from published hand-books, such as those published by FAO and available on the FAO Soils Portal[39] or from the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry*[40] is recommended. |
| Purpose of data: | Calculation of project emissions |
| Calculation method: | N/A |
| Comments: | |

## 9.3 Description of the Monitoring Plan

Project proponents must detail the procedures for collecting and reporting all data and parameters listed in Section 9.2. The monitoring plan must contain at least the following information:

1) Specification of the quantification approach applied (area-based or census-based). If using the census-based approach, clearly define the planting unit
2) A description of each monitoring task to be undertaken, and the technical requirements therein
3) Definition of the accounting boundary

[39] Available at http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/
[40] Intergovernmental Panel on Climate Change (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry*, IGES. https://www.ipcc.ch/publication/good-practice-guidance-for-land-use-land-use-change-and-forestry/

4) Parameters to be measured, including parameter tables for all directly measured tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations
5) Data to be collected and data collection techniques, documented in a standard operating procedure for field data collection. Sample designs will be specified (clearly delineate the sample population spatially, and justify sampling intensities and selection of sample units and sampling stages, where applicable) and un-biased estimators of population parameters identified that will be applied in calculations
6) Anticipated frequency of monitoring
7) Quality assurance and quality control (QA/QC) procedures to ensure accurate data collection and to screen for, and where necessary, correct, anomalous values, ensure completeness, perform independent checks on analysis results, and other safeguards as appropriate
8) Data archiving procedures, including procedures for any anticipated updates to electronic file formats. All data collected as part of monitoring processes, including QA/QC data, must be archived electronically and kept for at least two years after the end of the last project crediting period
9) Roles, responsibilities and capacity of monitoring team and management

# 10 REFERENCES

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Winjum, J. K., Brown, S., & Schlamadinger, B. (1998). Forest harvests and wood products: Sources and sinks of atmospheric carbon dioxide. *Forest Science*, *44*(2), 272–284. https://doi.org/10.1093/forestscience/44.2.272

# APPENDIX 1: PERFORMANCE METHOD

## Applicability Conditions

This appendix is applicable under the following conditions:

- All methodology applicability conditions detailed in Section 4 are met.
- The ARR activity can be clearly delineated spatially, and the area calculated using GIS.

## Baseline Scenario

The baseline scenario is represented by the business-as-usual growth of new vegetative stocking, based on observations from a representative control area outside of the project area. The control area is appropriately matched to the project area through the incorporation of bio-physical and demographic parameters correlated with probability of forest restoration/natural regeneration and productivity. The control area is used to track baseline growth of vegetation remotely; direct field measurement is not needed.

## Performance Benchmark

The performance benchmark is set equal to the average cumulative increase in estimated vegetative stocks (EVS) from their initial state, observed in designated control plots, relative to the project area. Methodology Equation A2 derives the performance benchmark for both demonstration of additionality and the crediting baseline. Methodology Equation (39) applies the performance benchmark for the crediting baseline. Performance benchmarks are developed independently for each project area. Performance benchmarks are set ex-ante, based on observations over the preceding five-year interval, and updated every five years. The approach to select the control area, outlined below, constitutes a matching approach widely used in impact evaluation in the environmental field.[41]

41 Ferraro, P. J., & Hanauer, M. M. (2014). Advances in measuring the environmental and social impacts of environmental programs. *Annual Review of Environment and Resources*, *39*, 495–517. https://doi.org/10.1146/annurev-environ-101813-013230

## Procedure to define the performance benchmark

**Step 1: Assess initial conditions in the project area for potential application of simplified performance benchmark**

Where both of the following are true at $t = 0$ (and at the beginning of all subsequent five-year evaluation periods):

1) Project area is located within a political jurisdiction where there are no government-funded programs providing incentives for tree planting in operation; and
2) Initial land use in the project area is continuous cropping (cultivation of an agricultural crop on the same site year after year, without any periods of fallow exceeding one season), demonstrated over 10 or more years prior to project start;

the value of $PB_t$ (performance benchmark applicable from year $t$ through year $t + 4$; percent) is set to zero. Otherwise, proceed to Step 2.

**Step 2: Delineate an eligible control area outside of the project area, applying matching factors**

Define project area and initial conditions (values at $t = 0$) for matching factors, and delineate the eligible (matched) control area outside of the project area (values at $t = -5$). All matching factors and source data specified in Table 5 must be incorporated in the delineation of the eligible control area. The process to determine the eligible control area is implemented with a series of GIS overlays. As necessary, stratify the eligible control area in cases where the project area bridges multiple exact match criteria (political boundaries, agro-ecological zones, initial non-forest land use, and/or land tenure). Where the project is a grouped project, factors in Table 5 are matched to the eligible geographic area and all relevant eligibility criteria for the grouped project, as set at project start ($t = 0$).

**Table 5: Required Factors and Source Data to Delineate Eligible Control Area, Evaluated at Time $t = -5$**

| Factor | Data Source/GIS Layer | Approach to Match Control to Project Area | Rationale |
|---|---|---|---|
| Political boundary | National boundary from published or official national government source<br><br>If a government-funded program providing incentives for tree planting/establishment is in operation at a subnational scale, the political boundary will be redefined as the subset of subnational political units with presence/absence of an incentives program | Exact | Similar policy environment |

| Factor | Data Source/GIS Layer | Approach to Match Control to Project Area | Rationale |
|---|---|---|---|
| | equal to the subnational political unit encompassing the project area. | | |
| **Outside any registered VCS AFOLU project** | kml files from VCS Project Database https://registry.verra.org/app/search/VCS | N/A | Absence of carbon finance = control |
| **Agro-ecological zone** | FAO GAEZ Database Using Variable AEZ classification by climate/soil/terrain/LC (57 classes)<br><br>Data can be accessed at https://gaez.fao.org/pages/data-viewer | Exact | Similar climate, soil, topography |
| **Initial proximity to nearest pre-existing forest cover** | Land use/land cover classification satisfying the following:<br>• Minimum non-forest/forest classification accuracy of 90% (referencing the methodology forest definition threshold of 25% canopy cover)<br>• Resolution not exceeding 100 meters<br>• Based on remote sensing observations within ±5 years of time $t = -5$ | Eligible control areas are those with distances to nearest forest cover at time $t = -5$ that do not exceed the mean value in the project area by more than 20%. | Similar extent of proximal seed sources |
| **Initial land use/land cover** | Land use/land cover classification(s) satisfying the following:<br>• Classification minimally distinguishes urban, cultivated agriculture, and grassland<br>• Minimum non-forest/forest classification accuracy of 90% (referencing the methodology forest definition threshold of 25% canopy cover)<br>• Resolution not exceeding 100 meters<br>• Non forest/forest classification must be based on remote sensing observations within ±1 year of time $t = -5$<br>• Non-forest land use classification must be based on remote sensing observations within ±5 years of time $t = -5$ | Exact | Similar initial non-forest land cover and pre-existing land management/ anthropogenic disturbance regime |
| **Land tenure** | Published or official government source<br><br>Minimally, land tenure classification will distinguish between public and private lands. More precise classifications (e.g., indigenous reserves, concessions, private industrial lands) may be used if available. | Exact | Similar actors |

**Step 3: Select approach to quantify estimated vegetative stocking (EVS)**

The performance benchmark is equal to the average cumulative increase in estimated vegetative stocking (EVS) from the initial state, observed in designated control plots, relative to the project area. EVS is quantified using one of the following approaches:

1) Percentage cover: EVS in the control plots is evaluated on the basis of percentage vegetative cover, applying the simplistic assumption that stocks are directly proportional to percentage cover. Vegetative cover will be defined as all aboveground biomass (live) pools included in the project boundary (i.e., tree, shrub, and/or herbaceous). This approach is best suited to activities involving tree and/or shrub planting, but not to herbaceous systems (due to the limitations of photo interpretation).

   Percentage cover is evaluated via direct visual inspection of Google Earth imagery, other high resolution (≤5 m) satellite imagery, or aerial photographs, using an approach such as the current version of the i-Tree Canopy tool.[42] Within each control plot, visually evaluate cover (e.g., tree/non-tree) at 50 random points and calculate and record percentage vegetative cover as the EVS value.

2) Remote sensing metric: EVS in the control plots is evaluated on the basis of a remote sensing metric with demonstrated correlation with biomass (e.g., Normalized Degradation Fraction Index[43] from Landsat imagery, or average canopy height derived from Lidar). The remote sensing metric applied must satisfy the following:

   a) Significant correlation with aboveground biomass (live) pools included in the project boundary (i.e., tree, shrub, and/or herbaceous) previously substantiated with published studies

   b) Validated with direct measurements of aboveground biomass (live) pools included in the project boundary (i.e., tree, shrub, and/or herbaceous) from the project region (collected from within the national boundary), demonstrating a statistically significant ($p < 0.05$) relationship

**Step 4: Select and monitor control plots from the eligible control area**

Step 4a. Select control plots

From within the eligible control area at time $t = -5$, select via simple random or stratified random sampling, 250 or more permanent virtual control plots.

[42] Available at https://canopy.itreetools.org/

[43] Souza Jr, C. M., Roberts, D. A., & Cochrane, M. A. (2005). Combining spectral and spatial information to map canopy damage from selective logging and forest fires. *Remote Sensing of Environment*, *98*(2–3), 329–343. https://doi.org/10.1016/j.rse.2005.07.013

Where EVS is defined using percentage cover, control plots are circular with a 56.4 meter radius (corresponding to a circle of 1-hectare area). Where EVS is defined using a remote sensing metric, control plots are defined as the aggregate of pixels most closely approximating a 1-hectare area.

In each control plot, assess and record initial ($t = -5$) EVS value. Exclude any plots with initial EVS exceeding ±10% of the project area value at time $t = 0$. EVS values will be derived by consulting the most recent imagery (at the evaluation date or up to two years prior). Note that the referenced ±10% is treated as a nominal value when applied to percentage cover, for example if percentage cover in the project area at $t = 0$ is 15%, then any selected control plots with percentage cover less than 5%, or exceeding 25%, are excluded.

Any plots determined to be in a forest use and temporarily un-stocked at $t = -5$ (e.g., recently cut plantation), confirmed via direct visual inspection of Google Earth imagery, other high resolution (≤5 m) satellite imagery, or aerial photographs (e.g., evident seedlings planted in rows or site surrounded by or adjacent to plantations), will also be excluded.

UTM coordinates of control plot centers meeting the above criteria will be recorded and fixed for the duration of the crediting period.

Step 4b. Re-evaluate EVS and calculate cumulative increase in EVS

At each evaluation event, remove any control plots in areas no longer matching the project area in terms of either:

1) Being subject to any subnational government-funded program providing incentives for tree planting, implemented during the evaluation period, to which the project area is not subjected, or
2) Land tenure, that is, an area where land tenure has been re-designated (e.g., private to public), referencing the same land tenure classification used at the initial time $t = -5$ delineation of the eligible control area.

Re-evaluate EVS, consulting the most recent imagery (at the evaluation date or up to two years prior). The observed cumulative increase in estimated vegetative stocking, EVS, is calculated as:

$$\Delta EVS_{control,i,t_{eval}} = MAX(EVS_{control,i,t_{eval}} - EVS_{control,i,t=-5}, 0) \quad \text{(A1)}$$

Where:

| | |
|---|---|
| $\Delta EVS_{control,i,t_{eval}}$ | Increase in estimated vegetative stocking (EVS) in control plot $i$, in the interval from $t = -5$ to $t_{eval}$ (year of last evaluation event) |
| $EVS_{control,i,t}$ | Estimated vegetative stocking (EVS) in control plot $i$ at time $t$ |
| $i$ | Control plot (1, 2, 3, …, $n$) |
| $t$ | Time elapsed since project start date (y) |

**Step 5: Derive performance benchmark**

The performance benchmark is then calculated as:

$$PB_t = t \times \frac{1}{t_{eval} - (t{=}-5)} \times \frac{1}{n} \times \sum_{i=1}^{n} \Delta EVS_{control,i,t_{eval}} \times \frac{1}{\Delta EVS_{WP,i,t}} \quad \text{(A2)}$$

Where:

| | |
|---|---|
| $PB_t$ | Performance benchmark applicable from year $t$ through year $t + 4$ (%) |
| $\Delta EVS_{control,i,t_{eval}}$ | Increase in estimated vegetative stocking (EVS) in control plot $i$ in the interval from $t = -5$ to $t_{eval}$ (year of last evaluation) |
| $\Delta EVS_{WP,i,t}$ | Increase in average estimated vegetative stocking (EVS) in the project area, in the interval from $t = 0$ to $T$ |
| $i$ | Control plot (1, 2, 3, …, $n$) |
| $t$ | Time elapsed since project start date (y) |
| $t_{eval}$ | Year of last evaluation (every 5 years) |

*Note — where the eligible control area is stratified, the performance benchmark is calculated by weighting each stratum by its areal representation in the project area.*

**Table 6: Illustrative Example of Performance Benchmark Derivation for a Project Starting in 2025, with Initial EVS (Percentage Canopy Cover) of 15%, and $n$ = 20 control plots. Performance Benchmarks Calculated for $t = 5$ and $t = 10$.**

| Control Plot | $EVS_{i,t} = -5$ (%) | $EVS_{i,t} = 0$ (%) | $EVS_{i,t} = 5$ (%) | Control Plot | $\Delta EVS_{control,i,t} = 0$ (%) | $\Delta EVS_{control,i,t} = 5$ (%) |
|---|---|---|---|---|---|---|
| 1 | 20 | 15 | 10 | 1 | 0 | 0 |
| 2 | 25 | 30 | 25 | 2 | 5 | 0 |
| 3 | 20 | 30 | 35 | 3 | 10 | 15 |
| 4 | 10 | 20 | 15 | 4 | 10 | 5 |
| 5 | 25 | 35 | 30 | 5 | 10 | 5 |
| 6 | 10 | 20 | 25 | 6 | 10 | 15 |
| 7 | 5 | 15 | 25 | 7 | 10 | 20 |
| 8 | 5 | 0 | 5 | 8 | 0 | 0 |
| 9 | 10 | 5 | 10 | 9 | 0 | 0 |
| 10 | 15 | 25 | 25 | 10 | 10 | 10 |
| 11 | 5 | 15 | 10 | 11 | 10 | 5 |
| 12 | 25 | 30 | 40 | 12 | 5 | 15 |
| 13 | 20 | 20 | 30 | 13 | 0 | 10 |
| 14 | 5 | 15 | 15 | 14 | 10 | 10 |
| 15 | 10 | 10 | 20 | 15 | 0 | 10 |
| 16 | 5 | 0 | 0 | 16 | 0 | 0 |
| 17 | 20 | 15 | 10 | 17 | 0 | 0 |
| 18 | 20 | 20 | 15 | 18 | 0 | 0 |
| 19 | 15 | 10 | 15 | 19 | 0 | 0 |
| 20 | 25 | 30 | 35 | 20 | 5 | 10 |
| | $EVS_{WP,t} = 0$ | $EVS_{WP,t} = 5$ | $EVS_{WP,t} = 10$ | $\Delta EVS_{control,t}$ | 5 | 7 |
| Project Area | 15 | 75 | 100 | $\Delta EVS_{WP,t}$ | 60 | 85 |
| | | | | $PB_t$ | 8 | 8 |

# APPENDIX 2: TESTING THE SIGNIFICANCE OF CARBON POOLS AND GHG EMISSIONS

This appendix outlines procedures for the determination of insignificant emission sources and/or changes in carbon pools.

The sum of decreases in carbon pools and increases in emissions that may be neglected must be less than 5% of the total decreases in carbon pools and increases in emissions, or less than 5% of $NGR$, whichever is lower.

$$RC_{Es} = \frac{Es}{\sum_{s=1}^{S} Es}$$

Where:

$RC_{Es}$ Relative contribution of each source $s$ to the sum of project and leakage GHG emissions

$Es$ GHG project emissions, leakage emissions, and decreases in carbon pools $s$

$s$ Sources of project and leakage GHG emissions, and decreases in carbon pools (1, 2, 3, …, $S$)

Rank the decreases in carbon pools and emissions in descending order of their relative contributions $RC_{Es}$ and order them according to their ranks (i.e., the lowest emission gets the highest rank and occupies the last position in the ordered sequence of emissions).

Calculate the cumulative sum of the relative contributions $RC_{Es}$ beginning with the lowest rank. Cease the summation when the cumulative sum reaches or exceeds the threshold of 0.95.

The GHG emissions, possible decreases in carbon pools, and leakage emissions not included in the summation are considered insignificant if their sum is lower than 5% of $NGR$. Otherwise, the procedure described above must be continued beyond the threshold of 0.95 until the above condition is met.