Draft VCS Methodology

M0274

ENHANCED FOREST SEQUESTRATION WITH DYNAMIC BASELINES USING RANDOMIZED CONTROL TRIALS

Draft Version

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Sectoral Scope 14: Forestry and Other Land Use

This draft methodology was developed by Funga PBC, Conservation International, CTrees, Ceiba PBC and The Nature Conservancy.

CONTENTS

1 SUMMARY DESCRIPTION

Additionality, Crediting Method, and Mitigation Outcome	
Additionality	Performance Method
Crediting Baseline	Performance Method
Mitigation Outcome	Removals

This methodology applies to improved forest management (IFM) activities with enhanced sequestration. Enhanced sequestration is achieved through forest management interventions that target discrete forest stands with treatments (e.g., fungal inoculation, liana removal) that increase the rate of carbon sequestration relative to typical forest management practices. These activities accelerate the growth of individual trees or forest stands selected for treatment. This methodology is globally applicable.

Although enhanced sequestration practices under this methodology may target individual trees or groups of trees (e.g., liana cutting, crown release, selective fertilization), the unit of accounting is the forest stand or stratum, rather than individual trees. Individual tree responses may be analyzed for silvicultural purposes, but crediting must not be based on comparisons between individual trees (e.g., treated versus untreated trees). Instead, crediting is based on the difference in stand- or stratum-level carbon stocks or stock changes between treatment (project) and control (baseline) areas.

This methodology uses a standardized method, employing a dynamic performance benchmark for establishing the baseline and demonstrating additionality. To accomplish this, an internal control (i.e., a discrete set of trees or stands within the project area where no intervention occurs) serves as a direct and dynamic baseline for measuring carbon benefits. The co-location of internal control and project plots is analogous to the design of experimental field trials used in agriculture and ecosystem science. This approach models randomized controlled trials and strengthens the ability to identify causal relationships between project intervention and changes in carbon stocks.

Furthermore, this methodology uses an external integrity benchmark to ensure control plots are an accurate representation of business-as-usual practices outside of the project boundary. This benchmark prevents control plot manipulation and is based on a remotely sensed stocking index.

Projects applying this methodology are not required to reassess their baseline validity at the baseline reassessment interval specified in the *VCS Standard*, since they use a dynamic performance benchmark for continual updates to the baseline. However, they are subject to all other baseline reassessment requirements in the most recent applicable version of the *VCS Standard*.

2 SOURCES

This methodology is based on the following VCS methodologies and tools:

- *VM0005 Methodology for Conversion of Low-Productive Forest to High-Productive Forest, v1.2*
- *VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.4*
- *VM0042 Methodology for Improved Agricultural Land Management, v2.0*
- *VM0045 Methodology for Improved Forest Management Using Dynamic Matched Baselines from National Forest Inventories, v1.2*
- *VM0047 Afforestation, Reforestation, and Revegetation, v1.1*
- *Agriculture, Forestry, and Other Land Use (AFOLU) Non-Permanence Risk Tool, v4.2*

This methodology uses the most recent applicable versions of the following tools and modules:

- Harvested Wood Products Module (forthcoming)
- *VT0008 Additionality Assessment*
- Timber Leakage Assessment Tool (forthcoming)

3 DEFINITIONS

Enhanced sequestration treatment
Intervention to increase the overall rate of carbon sequestration relative to typical forest management practices by improving individual tree growth rates and survival (e.g., liana or vine removal; fungal inoculation, nutrient amendments).

External benchmark plot
Additional location outside of the project area where tree's or stand growth is tracked to determine whether internal control plots are representative of a business-as-usual scenario (i.e., matched non-treatment area).

Internal control plot
Forest sample plot that is not subject to project activity treatments, that represents business-as-usual operations within the project area, and that is a fixed and distinguishable area that contains at least one tree and is monumented (i.e., permanently marked in the field using physical reference points to allow repeated measurements).

Managed forests
Forest lands actively managed for production of wood products, including saw timber, pulpwood, and fuelwood. This includes both plantation forests and natural forests (primary and secondary) where harvesting or other silvicultural activities occur.

Project plot
Forest sample plot that is subject to project activity treatments in the project area and is a fixed and distinguishable area that is monumented to allow repeated measurements.

Sample unit
A sample unit constitutes a measured and monitored permanent plot pair: one internal control plot that does not receive treatment, and one project plot that does receive treatment.

Stand
A contiguous, defined area composed of trees sufficiently uniform in age-class distribution, composition, and structure and growing on a site of sufficiently uniform quality to be a distinguishable unit. Relevant in accounting as a primary building block (i.e., a minimum mapping unit of variable size) for quantifying project area and identifying areas subject to harvest or disturbance.[1]

Stocking index
An unspecified remote sensing metric with demonstrated correlation with terrestrial aboveground carbon stocks (e.g., normalized difference fraction index from Landsat imagery, average canopy height derived from LiDAR, or percentage canopy cover interpreted from aerial imagery).

Treatment exclusion zone
Area around internal control plots that does not receive the treatment applied to the project area and is not monitored as part of a control plot, with the explicit intent to isolate controls from the project activity.

[1] Adapted from Helms, J. A. (Ed.). 1998. *Dictionary of Forestry*. Society of American Foresters.

4 APPLICABILITY CONDITIONS

This methodology is globally applicable to IFM project activities with enhanced sequestration treatments that are classified under "forests remaining as forests." This methodology is applicable under the following conditions:

1. All activities take place on forest lands that will remain forested for the entire crediting period and may include:

    a. forests that are or have been subject to a history of severe anthropogenic disturbance (e.g., prior forest canopy removal) and/or active management in the past 10 years.

    b. projects on lands subject to timber harvest; project proponents must demonstrate that harvest rotation lengths within the project area are not less than regional business-as-usual or legal minimum rotation lengths (whichever is longer). Documents demonstrating that project harvest rotation lengths are not less than regional rotation lengths must be submitted at validation.

    c. natural forests (i.e., not managed for wood products) that have experienced natural disturbances (e.g., windthrow, pest infestation).

In addition to the *VCS Standard*'s environmental safeguards, projects must also avoid unintended ecological impacts on implementation areas and adjacent or external ecosystems through the application of novel treatments. Projects must provide the following documentation for every type of project intervention planned as part of project activities:

2. Documentation of no known adverse ecological impacts:

    a. Evidence-Based Validation: Provide peer-reviewed scientific literature or published risk assessments confirming that the proposed treatment has no known significant adverse ecological impacts; or

    b. Expert Attestation: Where published evidence is insufficient, provide an official attestation from a qualified independent institution (e.g., a recognized academic body, government agency, or established environmental/conservation consultancy). This attestation must certify that the treatment is reasonably safe based on the specific parameters of the project treatment.

3. Preventative measures:

    a. Non-Native & Novel Organisms: Projects must identify and mitigate any potential for the unintended introduction or expansion of non-native species or novel organisms (including GMOs and synthetic toxins) resulting from system inputs or the removal of biological material; and

    b. Containment: Projects must describe specific containment measures or buffer zones designed to prevent ecological spillover; and

c. Pathogen and Invasive Species Screening: Projects must prevent pathogen and invasive species introduction. Formal procedures and results for screening inputs for pathogens or invasive species must be documented and follow a peer-reviewed process relevant to the organism group.

4. Responsible Sourcing:

   a. Projects must verify and report the provenance of all biological inputs to ensure they are not sourced from—or in a manner that degrades—Protected Areas, intact primary forests, or High Conservation Value (HCV) areas; and

   b. Projects must describe robust methods to avoid direct or indirect impacts on threatened or endangered species listed in the IUCN Red List[2] and CITES Appendices[3]. This includes active prevention of invasive species expansion potentially triggered by project activities.

This methodology is not applicable under the following conditions:

1. Project activities involve treatments that cannot be effectively limited to a discrete unit area that is not larger than the size of the project and internal control plots.
2. Soil disturbance due to project activities exceeds 5% of the implementation area.4
3. Project activities occurring on organic soils or in (tidal) wetlands (e.g., mangroves, salt marshes) and result in manipulation of the water table.

5 PROJECT BOUNDARY

Implementation area

The spatial extent of the project that encompasses all lands subject to implementation of project activities, excluding the areas within the project boundary that are designated as internal control plots and treatment exclusion zones.

Project emissions and carbon dioxide removals must be accounted for over the entire implementation area.

Greenhouse gas (GHG) boundary

Selected carbon pools and sources included in the project boundary are listed in Tables 1 and 2. The significance of these must be demonstrated using the *de minimis* equation in Appendix 2.

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[2] IUCN. The IUCN Red List of Threatened Species. Version 2025-2. https://www.iucnredlist.org

[3] CITES. The CITES Appendices I, II and III. Convention on International Trade in Endangered Species of Wild Fauna and Flora. Available at: https://cites.org/eng/app/appendices.php

[4] This is to ensure minimal impact on the ecosystem's natural processes and functions.

Temporal boundary

The project start date and project crediting period must be established in accordance with the rules and requirements set out in the most recent version of the *VCS Standard*.

Appendix 2 of this methodology must be applied to test the significance of carbon pools and GHG emission sources to determine whether they are *de minimis*. Overall, specific carbon pools and GHG sources that cause project emissions may be deemed *de minimis* and do not have to be accounted for, where together the sum of all decreases in carbon stocks or increases in GHG emissions (from GHG sources) amounts to less than 5% of the total reductions and/or removals generated by the project.

Table 1. Carbon pools accounted for in the project boundary and as leakage

Source	Included?	Justification/Explanation
Aboveground tree biomass	Yes	Required pool. Expected to be subject to significant change due to the project activity.
Aboveground woody non-tree biomass	Yes/optional	Must be included if not *de minimis*. For other cases, this carbon pool is optional.
Aboveground non-tree herbaceous biomass	No	Not required due to insignificance.
Belowground tree biomass	Yes	Required pool. Expected to be subject to significant change due to the project activity.
Belowground woody non-tree biomass	Yes/optional	Must be included if not *de minimis*. For other cases, this carbon pool is optional.
Dead wood	Yes/optional	Accounting boundary restricted to standing dead wood (lying dead wood is not included). Must be included if not *de minimis*. For other cases, this carbon pool is optional.
Litter	No	Not required due to insignificance.
Soil organic carbon	No	Excluded due to constraints in Applicability Condition Section 4.
Wood products	Yes	Required pool.

Table 2. GHG sources and sinks accounted for as baseline, project, and leakage emissions

Source/Sink		Type	Gas	Included/Excluded	Justification/Explanation
Baseline and project	Application of nitrogen-containing soil amendments or decomposition of plant materials with fixed nitrogen	Source	CO_2	Depends on project activity	CO_2 emissions must be included where machines are used to apply fertilizer in the project and baseline scenario.
			CH_4	Excluded	Decomposition in well-drained upland forest soils is strictly aerobic. Projects on organic soils or wetlands, where anaerobic CH_4 production occurs, are excluded by the applicability conditions.
			N_2O	Depends on project activity	Included where nitrogen fertilizer is applied as part of the project activity. N_2O emissions are conservatively set to zero in the baseline.
			Other	No	N/A
	Burning of tree biomass	Source	CO_2	Depends on project activity	Must be included in both the baseline and project scenario where incidence and/or severity of fires is impacted by the project activity (e.g., where the project activity involves burning woody biomass or alters the probability and/or magnitude of emissions from forest fires). Emissions from burning non-tree biomass are not
			CH_4	Depends on project activity	
			N_2O	Depends on project activity	

					included because they are *de minimis*.
			Other	None	N/A
	Burning of fossil fuels	Source	CO_2	Depends on project activity	*De minimis*, defined by equation in Appendix 2.
			CH_4	Excluded	*De minimis*, defined by equation in Appendix 2.
			N_2O	Excluded	*De minimis*, defined by equation in Appendix 2.
			Other	Excluded	*De minimis*, defined by equation in Appendix 2.

6 BASELINE SCENARIO

The crediting baseline for this methodology uses a dynamic performance benchmark approach, where the baseline scenario is represented by designated internal control plots that are continually monitored. Each internal control plot is paired with one project plot through a k-nearest neighbor approach described in Appendix 1. Together, the paired project plot and internal control plot form the sample unit. The internal control plot and project plot within a sample unit must be measured concurrently at all monitoring events. Internal control plots are used to establish and update the dynamic performance benchmark against which project plots are compared.

The internal control plots must be established via a 1:1 matching process with project plots in accordance with the procedure described in A1.2 in Appendix 1. Control and project plots must avoid differential treatment by land managers.

6.1 Time Zero Measurements (t = 0)

All projects must establish t = 0 carbon stock measurements for all significant carbon pools in both project and internal control plots. The measurements must meet the following requirements:

1) Measurements represent site conditions prior to the commencement of any treatment activities which alter carbon stocks (including site preparation) that significantly influence carbon emissions or removals. t = 0 measurements must be completed concurrently for each pair of plots before treatment occurs within the project plot of the sample unit.

2) Measurements taken up to two years before or after the start of treatment activities in the project area may be used as $t = 0$ measurements. Within a given project, treatment activities in any individual plot may begin up to two years after activities commenced in the first plot.

3) Any specific sample unit for which $t = 0$ measurement is not completed prior to treatment activities in the project plot cannot be included in the monitoring, reporting, and verification process. Treatment activities may be underway elsewhere in the project, stratum, or instance before $t = 0$ measurements are complete for all plots; however, for any given paired sample unit, no treatment activity may begin in the project plot until its $t = 0$ measurement has been taken. As specified in Appendix 1, the project proponent must ensure careful planning and implementation across three key areas:

    a) Internal control plot placement

    b) Project plot placement

    c) External benchmark plot placement

6.2 External Benchmark Plots

External benchmark plots must be established outside the project area in accordance with the procedures and requirements in the A1.3 (Integrity Benchmark) in Appendix 1 to validate the internal control plots. A donor pool of external benchmark plots is selected based on matching covariates such as carbon stock and growth indices. Using *k*-nearest neighbor matching, these benchmarks are paired with internal control plots, ensuring that control conditions accurately reflect regional, business-as-usual scenarios.

To confirm benchmark validity, external benchmark and internal control plots are assessed using stocking indices (SI) and time series analysis. External benchmark plots established at the start of the project are reassessed for each verification to maintain alignment with business-as-usual conditions.

As outlined in A1.3.3 in Appendix 1, where a project fails the integrity benchmark at verification, the project cannot generate any further Verified Carbon Units (VCUs). VCUs that have already been issued are unaffected.

6.3 Baseline Reassessment

Projects applying this methodology are not required to reassess their baseline validity at the baseline reassessment interval specified in the *VCS Standard* since they use a dynamic performance benchmark for continual updates to the baseline. However, they are subject to all other baseline reassessment requirements in the most recent applicable version of the *VCS Standard*.

7 ADDITIONALITY

This methodology uses a performance method for the demonstration of additionality, with the following steps:

1) Regulatory surplus
2) Performance benchmark
3) Additionality Assessment

Step 1: Regulatory surplus
Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the most recent applicable version of the *VCS Standard*.

Step 2: Performance benchmark
A project meets the performance benchmark where net removals across the entire project in the monitoring interval are significantly greater than zero using a one-sided paired t-test, as described below. This analysis uses data from the internal control plots that represent the baseline scenario, and project plots that represent the with-project scenario.

For projects that are not stratified, set $s = 1$. For projects that are stratified, a weighted, paired, one-sided t-test is used that considers both the variance in the paired plots and the weights associated with each stratum's area, as follows:

1) First, calculate the mean net removals across all sample units in each stratum s in year *t*:

$$\overline{CR_{s,t}} = \frac{1}{n_{s,t}} \sum_{i=1}^{n_{s,t}} \Delta CO2_{wp,i,s,t-bsl,i,s,t} \tag{1}$$

Where:

$\overline{CR_{s,t}}$	Mean removals in year *t* across all sample units in stratum s (t CO_2e per unit area per year)
$\Delta CO2_{wp,i,s,t-bsl,i,s,t}$	Difference in carbon stock change between each sample unit *i* (pair of project and internal control plots) in stratum s (t CO_2e per unit area per year)
$n_{s,t}$	Number of sample units in which stock change values are available in stratum s in year *t*

2) Calculate the standard deviation for each stratum in year *t*:

$$\hat{\sigma}_{s,t} = \sqrt{\frac{1}{n_{s,t}-1}\sum_{i=1}^{n_{s,t}}\left(\Delta CO2_{wp,i,s,t-bsl,i,s,t} - \overline{CR_{s,t}}\right)^2}$$

(2)

Where:

$\hat{\sigma}_{s,t}$	Standard deviation for stratum s in year *t*
$\overline{CR_{s,t}}$	Mean removals in year *t* across all sample units in stratum s (t CO_2e per unit area per year)
$\Delta CO2_{wp,i,s,t-bsl,i,s,t}$	Difference in carbon stock change between each sample unit *i* (pair of project and internal control plots) in stratum s (t CO_2e per unit area per year)
$n_{s,t}$	Number of sample units in which stock change values are available in stratum s in year *t*

3) Combine the stratum means and stratum weights to calculate the overall weighted mean in year *t*:

$$CR_{weight,t} = \frac{\sum_{s=1}^{S_t} w_{s,t}\overline{CR_{s,t}}}{\sum_{s=1}^{S_t} w_{s,t}}$$

$$w_{s,t} = \frac{A_{s,t}}{A_{total,t}}$$

(3)

Where:

$CR_{weight,t}$	*Weighted* mean removals across all strata in year *t* (t CO_2e per unit area per year)
$\overline{CR_{s,t}}$	Mean removals in year *t* across all sample units in stratum *s* (t CO_2e per unit area per year)
$w_{s,t}$	Weight for stratum s, calculated as the stratum area divided by the total project area in year *t*
S_t	Total number of strata in year *t*

$A_{s,t}$	Implementation area in stratum s in year *t* (unit area)
$A_{total,t}$	Total implementation area in year *t* (unit area)
$n_{s,t}$	Number of sample units in which stock change values are available in stratum s in year *t*

4) Calculate the standard error of the weighted mean in year *t* to account for the variability within each stratum s:

$$\sigma^2{}_{W,s,t} = w_{s,t}^2 \frac{\hat{\sigma}_{s,t}^2}{n_{s,t}}$$

$$w_{s,t} = \frac{A_{s,t}}{A_{total,t}}$$

$$SE\left(CR_{weight,t}\right) = \sqrt{\frac{1}{\left(\sum_{s=1}^{S_t} w_{s,t}\right)^2} \sum_{s=1}^{S_t} \sigma^2{}_{W,s,t}} \tag{4}$$

Where:

$\sigma^2{}_{W,s,t}$	*Weighted* variance of removals in strata s in year *t*
$w_{s,t}$	Weight for stratum s, calculated as the stratum area divided by the total project area in year *t*
S_t	Total number of strata in year *t*
$A_{s,t}$	Implementation area in stratum s in year *t* (unit area)
$A_{total,t}$	Total implementation area in year *t* (unit area)
$n_{s,t}$	Number of sample units in which stock change values are available in stratum s in year *t*

5) Calculate the t-statistic (τ_t) in year *t*:

$$\tau_t = \frac{CR_{weight,t}}{SE\left(CR_{weight,t}\right)} \tag{5}$$

Where:

τ_t	t-statistic in year *t*
$CR_{weight,t}$	*Weighted* mean removals across all strata in year *t* (t CO_2e per unit area per year)

$SE(CR_{weight,t})$	Standard error of the weighted mean removals across all strata in year *t*

6) Determine the critical *t*-value for a 95% confidence level in year *t* ($\tau_{critical,t}$). Since weights depend on both variance within strata and sample sizes, estimate the degrees of freedom using the Welch–Satterthwaite formula in Equation 6. Then, obtain the critical value from a standard *t*-distribution lookup table (or with equivalent software) for a one-sided upper-tail t-test at a significance level of 0.05, using the estimated degrees of freedom.

$$df_t = \left(\frac{\left(\sum_{s=1}^{S_t} \sigma^2{}_{W,s,t}\right)^2}{\sum_{s=1}^{S_t} \frac{\sigma^2{}_{W,s,t}}{n_{s,t} - 1}} \right) \tag{6}$$

The project passes the performance benchmark in year *t* if the test statistic is greater than the critical t-value for that year if $\tau_t > \tau_{critical,t}$, then the project is additional in year *t.* If a project does not pass the performance benchmark in a given year *t*, project proponents will not receive VCUs for year *t*.

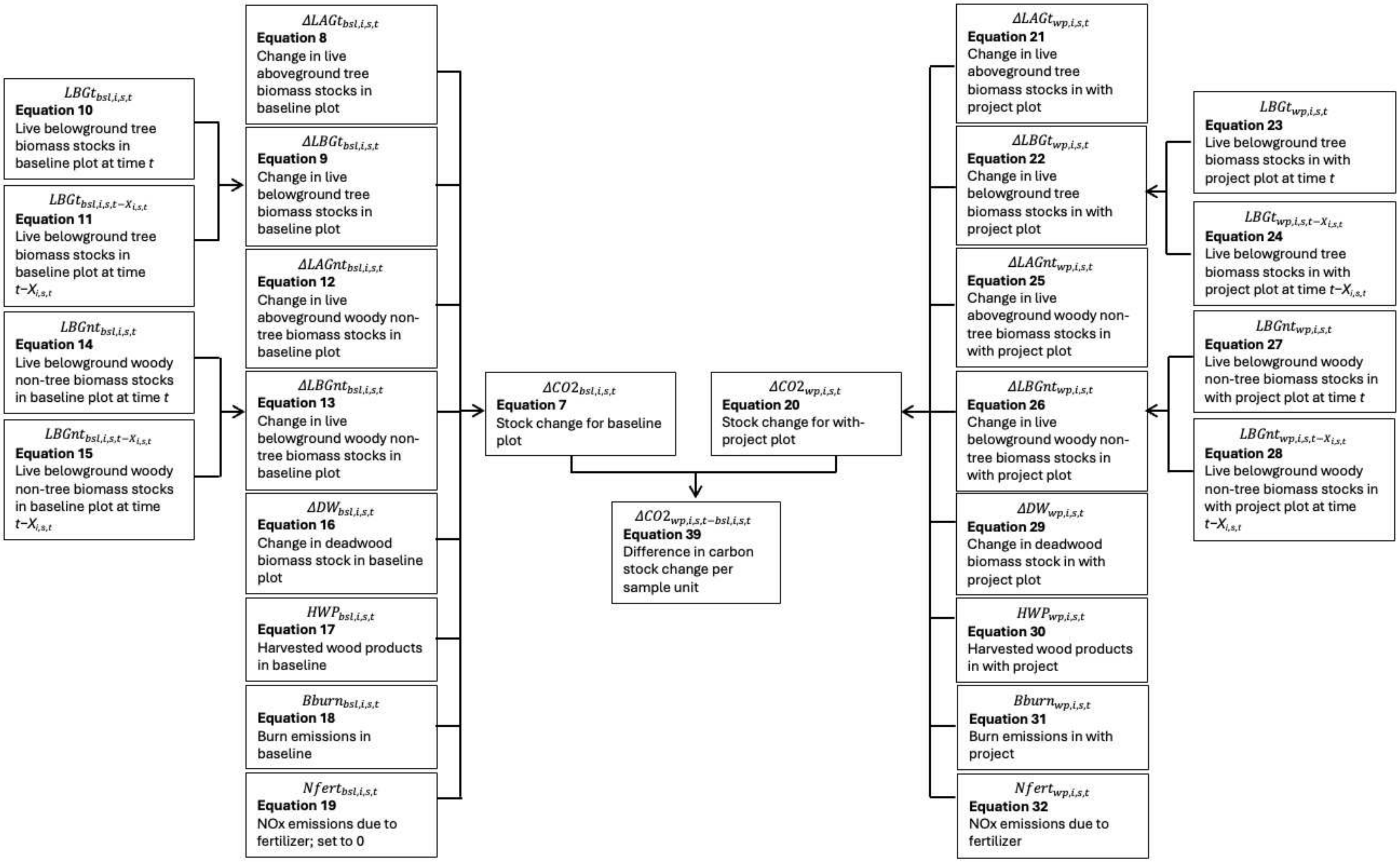
Step 3: Additionality Assessment

Project proponents must apply the procedures and requirements in the most recent applicable version of the *VT0008 Additionality Assessment* tool.

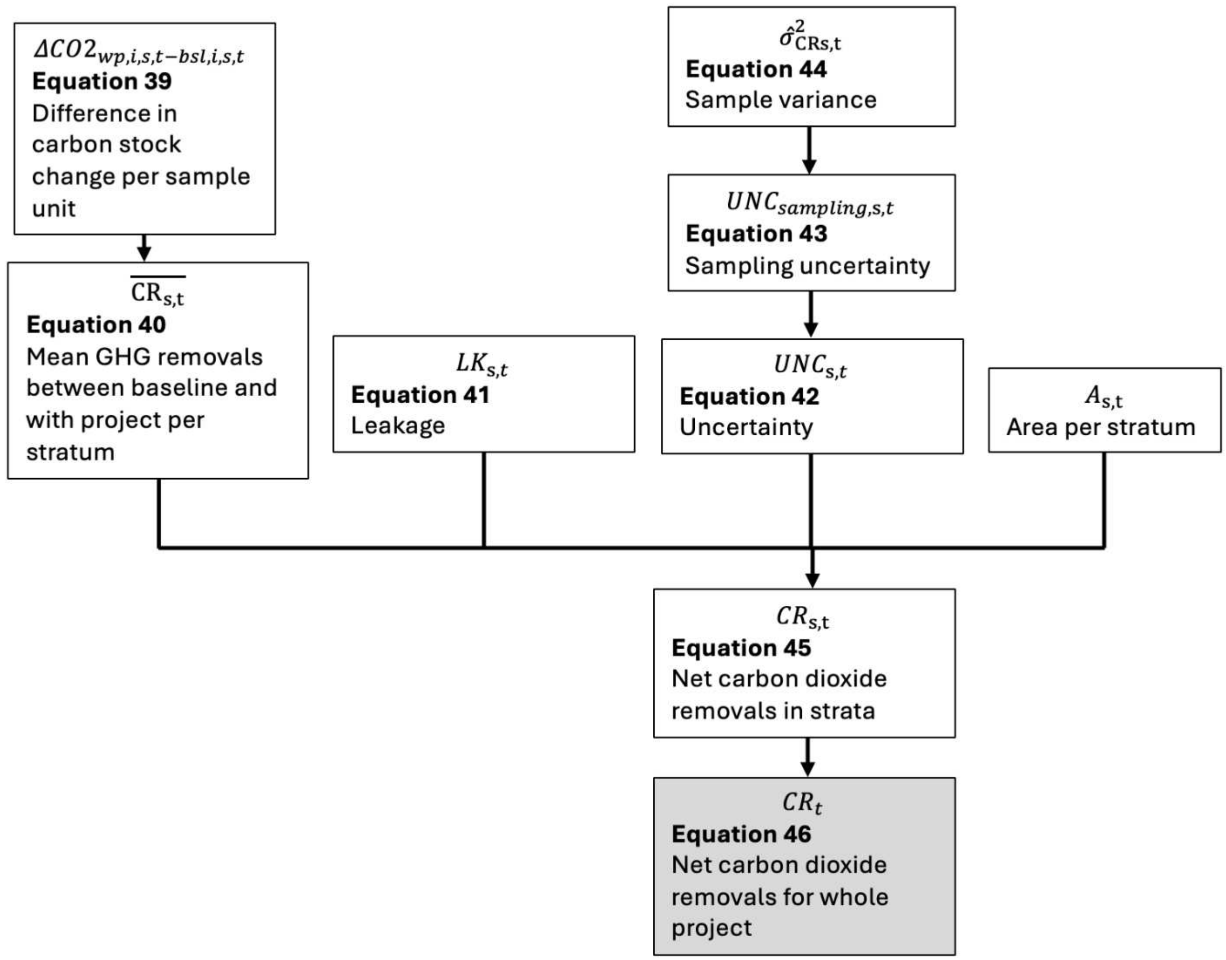
If a project does not pass the regulatory surplus test, the performance benchmark test, and the additionality assessment, the project is not additional.

8 QUANTIFICATION OF REDUCTIONS AND REMOVALS

This methodology yields only GHG removals. Equation Maps 1 and 2 provide an overview of the equations needed to calculate removals.



Equation Map 1: Equation map for calculating the difference in carbon stock change per sample unit.



Equation Map 2: Equation map for calculating net carbon dioxide removals. These equations follow from Equation Map 1.

8.1 Stock change quantification guidance

Measurements to calculate stock change are taken in each sample unit *i*. Both plots within each sample unit must be monitored on the same schedule within 30 days of each other.[5]

Where monitoring is conducted during the middle of a project year (with project years calculated from the project activity start date), the length of the monitoring period must be rounded to the nearest whole year as follows:

- If the monitoring event occurs six months or less after the most recent project year anniversary, the period must be rounded down to the preceding whole year.
- If the monitoring event occurs more than six months after the most recent project year anniversary, the period must be rounded up to the following whole year.

For example, for a project with a project activity start date of 1 February 2025, a first monitoring event (t = 0) concluding on 1 January 2025, and a second monitoring event concluding on 1 June 2027, the elapsed time from the first to the second monitoring event is two years and five months and must be rounded down to two years. If the second monitoring event concluded instead on 1 July 2027, the elapsed time between the two monitoring events would be two years and six months and must be rounded up to three years.

8.2 Baseline Removals

8.2.1 Baseline Scenario Total Stock Change

Stock change in the baseline scenario is estimated for each internal control plot in sample unit *i* in stratum s in year *t* using Equation (7) (net sequestration).[6]

$$\Delta CO2_{bsl,i,s,t} = \Delta LAGt_{bsl,i,s,t} + \Delta LBGt_{bsl,i,s,t} + \Delta LAGnt_{bsl,i,s,t} + \Delta LBGnt_{bsl,i,s,t} + \Delta DW_{bsl,i,s,t} + HWP_{bsl,i,s,t} - Bburn_{bsl,i,s,t} - Nfert_{bsl,i,s,t} \quad (7)$$

Where:

$\Delta CO2_{bsl,i,s,t}$	Stock change in the internal control plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)

[5] Project plots are denoted as with-project through “wp” subscripts throughout this methodology.

[6] Must include all pools that are deemed significant as per Appendix 2 Equation A2.1.

$\Delta LAGt_{bsl,i,s,t}$ Change in live aboveground tree biomass stocks in the internal control plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)

$\Delta LBGt_{bsl,i,s,t}$ Change in live belowground tree biomass stocks in the internal control plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)

$\Delta LAGnt_{bsl,i,s,t}$ Change in live aboveground non-tree biomass stocks in the internal control plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)

$\Delta LBGnt_{bsl,i,s,t}$ Change in live belowground non-tree biomass stocks in the internal control plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)

$\Delta DW_{bsl,i,s,t}$ Change in dead wood biomass stocks in the internal control plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)

$HWP_{bsl,i,s,t}$ Harvested wood products remaining stored over 100 in the internal control plot in sample unit *i* in stratum s, harvested in year t (t CO_2e per unit area per year)

$Bburn_{bsl,i,s,t}$ Emissions of methane and nitrous oxide in the internal control plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)

$Nfert_{bsl,i,s,t}$ Direct and indirect nitrous oxide emissions due to nitrogen fertilizer use in the internal control plot in sample unit *i* in stratum s in year *t*; conservatively set to zero (t CO_2e per unit area per year)

i = 1, 2, 3,..., *n* sample units

s = 1, 2, 3,..., *S* strata; s = 1 for projects without stratification

t = 1, 2, 3,..., *T* years elapsed since the project start date

8.2.2 Live Aboveground Tree Biomass

$$\Delta LAGt_{bsl,i,s,t} = \left(LAGt_{bsl,i,s,t} - LAGt_{bsl,i,s,t-X_{i,s,t}}\right) \times \left(1/X_{i,s,t}\right) \times \left(\frac{44}{12}\right) \times CF \quad (8)$$

Where:

$\Delta LAGt_{bsl,i,s,t}$ Change in live aboveground tree biomass stocks in the internal control plot in sample unit *i* in stratum *s* in the monitoring interval ending at time *t* (t CO_2e per unit area per year)

$LAGt_{bsl,i,s,t}$ Live aboveground tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)

$LAGt_{bsl,i,s,t-X_{i,s,t}}$	Live aboveground tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)
CF	Carbon fraction of dry biomass (t C/t d.m.)

8.2.3 Live Belowground Tree Biomass

$$\Delta LBGt_{bsl,i,s,t} = \left(LBGt_{bsl,i,s,t} - LBGt_{bsl,i,s,t-X_{i,s,t}}\right) \times \left(1/X_{i,s,t}\right) \times \left(\frac{44}{12}\right) \times CF \tag{9}$$

Where:

$\Delta LBGt_{bsl,i,s,t}$	Change in live belowground tree biomass stocks in the internal control plot in sample unit *i* in stratum *s* in the monitoring interval ending in year *t* (t CO_2e per unit area per year)
$LBGt_{bsl,i,s,t}$	Live belowground tree biomass stocks in the internal control plot in sample unit *i* in stratum s in year *t* (t biomass per unit area)
$LBGt_{bsl,i,s,t-X_{i,s,t}}$	Live belowground tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum *s* ending at time *t* (years)
CF	Carbon fraction of dry biomass (t C/t d.m.)

$$LBGt_{bsl,i,s,t} = LAGt_{bsl,i,s,t} \times R \tag{10}$$

Where:

$LBGt_{bsl,i,s,t}$	Live belowground tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)
$LAGt_{bsl,i,s,t}$	Live aboveground tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)

R Root-to-shoot ratio of aboveground tree biomass to belowground tree biomass and aboveground woody non-tree biomass to belowground woody non-tree biomass

$$LBGt_{bsl,i,s,t-X_{i,s,t}} = LAGt_{bsl,i,s,t-X_{i,s,t}} \times R$$

(11)

Where:

$LBGt_{bsl,i,s,t-X_{i,s,t}}$ Live belowground tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)

$LAGt_{bsl,i,s,t-X_{i,s,t}}$ Live aboveground tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)

$X_{i,s,t}$ Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)

R Root-to-shoot ratio of aboveground tree biomass to belowground tree biomass and aboveground woody non-tree biomass to belowground woody non-tree biomass

8.2.4 Live Aboveground Woody Non-Tree Biomass

$$\Delta LAGnt_{bsl,i,s,t} = \left(LAGnt_{bsl,i,s,t} - LAGnt_{bsl,i,s,t-X_{i,s,t}}\right) \times \left(1/X_{i,s,t}\right) \times \left(\frac{44}{12}\right) \times CF$$

(12)

Where:

$\Delta LAGnt_{bsl,i,s,t}$ Change in live aboveground woody non-tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area per year)

$LAGnt_{bsl,i,s,t}$ Live aboveground woody non-tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)

$LAGnt_{bsl,i,s,t-X_{i,s,t}}$ Live aboveground woody non-tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)

$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)
CF	Carbon fraction of dry biomass (t C/t d.m.)

8.2.5 Live Belowground Woody Non-Tree Biomass

$$\Delta LBGnt_{bsl,i,s,t} = \left(LBGnt_{bsl,i,s,t} - LBGnt_{bsl,i,s,t-X_{i,s,t}}\right) \times \left(1/X_{i,s,t}\right) \times \left(\frac{44}{12}\right) \times CF \tag{13}$$

Where:

$\Delta LBGnt_{bsl,i,s,t}$	Change in live belowground woody non-tree biomass stocks in the internal control plot in sample unit *i* in stratum *s* in the monitoring interval ending at time *t* (t CO_2e per unit area per year)
$LBGnt_{bsl,i,s,t}$	Live belowground woody non-tree biomass stocks in the internal control plot in sample unit *i* in stratum s in year *t* (t biomass per unit area)
$LBGnt_{bsl,i,s,t-X_{i,s,t}}$	Live belowground woody non-tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)
CF	Carbon fraction of dry biomass (t C/t d.m.)

$$LBGnt_{bsl,i,s,t} = LAGnt_{bsl,i,s,t} \times R \tag{14}$$

Where:

$LBGnt_{bsl,i,s,t}$	Live belowground woody non-tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)
$LAGnt_{bsl,i,s,t}$	Live aboveground woody non-tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)
R	Root-to-shoot ratio of aboveground tree biomass to belowground tree biomass and aboveground woody non-tree biomass to belowground woody non-tree biomass

$$LBGnt_{bsl,i,s,t-X_{i,s,t}} = LAGnt_{bsl,i,s,t-X_{i,s,t}} \times R$$

(15)

Where:

$LBGnt_{bsl,i,s,t-X_{i,s,t}}$	Live belowground woody non-tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
$LAGnt_{bsl,i,s,t-X_{i,s,t}}$	Live aboveground woody non-tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum s ending in year *t* (years)
R	Root-to-shoot ratio of aboveground tree biomass to belowground tree biomass and aboveground woody non-tree biomass to belowground woody non-tree biomass

8.2.6 Dead Wood Biomass

Changes in dead wood biomass ($\Delta DW_{bsl,i,s,t}$) are calculated using Equation 16 below:

$$\Delta DW_{bsl,i,s,t} = \left(DW_{bsl,i,s,t} - DW_{bsl,i,s,t-X_{i,s,t}}\right) \times \left(1/X_{i,s,t}\right) \times \left(\frac{44}{12}\right) \times CF$$

(16)

Where:

$\Delta DW_{bsl,i,s,t}$	Change in dead wood biomass stocks in the internal control plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)
$DW_{bsl,i,s,t}$	Dead wood biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)
$DW_{bsl,i,s,t-X_{i,s,t}}$	Dead wood biomass stocks in each internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum s ending in year *t* (years)
CF	Carbon fraction of dry biomass (t C/t d.m.)

8.2.7 Harvested Wood Products

Harvested wood product stocks ($HWP_{bsl,i,s,t}$) are calculated using Equation (17).

$$HWP_{bsl,i,s,t} = ((BBremoved_{saw,wt=sfw,bsl,i,s,t} \times SF_{saw,wt}) + (BBremoved_{pulp,wt=sfw,bsl,i,s,t} \times SF_{pulp,wt}) + (BBremoved_{saw,wt=hwd,bsl,i,s,t} \times SF_{saw,wt}) + (BBremoved_{pulp,wt=hwd,bsl,i,s,t} \times SF_{pulp,wt})) \times (1/X_{i,s,t}) \times \left(\frac{44}{12}\right) \times CF \quad (17)$$

Where:

$HWP_{bsl,i,s,t}$	Harvested wood products remaining stored for 100 years for the internal control plot in sample unit *i* in stratum s, harvested in the monitoring interval ending at time *t* (t CO_2e per unit area per year)
$BBremoved_{saw,wt,bsl,i,s,t}$	Saw log bole biomass stocks in wood type *wt* in commercial species removed from the internal control plot in sample unit *i* in stratum s, harvested in the monitoring interval ending at time *t* (t biomass per unit area)
$BBremoved_{pulp,wt,bsl,i,s,t}$	Pulpwood bole biomass stocks in wood type *wt* in commercial species removed from the internal control plot in sample unit *i* in stratum s, harvested in the monitoring interval ending at time *t* (t biomass per unit area)
$SF_{saw,wt}$	Saw log 100-year average storage factor (mass remaining stored in use and landfills over 100 years) for wood type *wt* (dimensionless)
$SF_{pulp,wt}$	Pulpwood 100-year average storage factor (mass remaining stored in use and landfills over 100 years) for wood type *wt* (dimensionless)
$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)
CF	Carbon fraction of dry biomass (t C/t d.m.)
wt	Wood type, defined as softwood (sfw) or hardwood (hwd)

8.2.8 Burning of Biomass

Where burning occurs in the monitoring interval ending at time *t*, it is assumed that all stock change is subject to burning, and methane and nitrous oxide emissions from fire are included and calculated using Equation (18). Otherwise, $Bburn_{bsl,i,s,t}$ is set equal to zero.

$$Bburn_{bsl,i,s,t} = \left(1/X_{i,s,t}\right) \times (\sum_{g=1}^{G} \quad GWP_g \times ((LAGt_{bsl,i,s,t} - LAGt_{bsl,i,s,t-X_{bsl,i,s,t}}) + (LAGnt_{bsl,i,s,t} - LAGnt_{bsl,i,s,t-X_{bsl,i,s,t}})$$

$$+ (DW_{bsl,i,s,t} - DW_{bsl,i,s,t-X_{bsl,i,s,t}})) \times \left(\frac{44}{12}\right) \times CF \times C_f \times EF_g \times 10^{-3})$$

(18)

Where:

$Bburn_{bsl,i,s,t}$	Emissions of methane and nitrous oxide in the internal control plot in sample unit *i* in stratum s, in the monitoring interval ending at time *t* (t CO_2e per unit area per year)
$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum *s* ending at time *t* (years)
GWP_g	Global warming potential of gas *g* (dimensionless)
$LAGt_{bsl,i,s,t}$	Live aboveground tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)
$LAGt_{bsl,i,s,t-X_{i,s,t}}$	Live aboveground tree biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
$LAGnt_{bsl,i,s,t}$	Live aboveground woody non-tree biomass stocks in the internal control plot in sample unit *i* in stratum *s* in the monitoring interval ending at time *t* (t biomass per unit area)
$LAGnt_{bsl,i,s,t-X_{i,s,t}}$	Live aboveground woody non-tree biomass stocks in the internal control plot in sample unit *i* in stratum *s* in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
$DW_{bsl,i,s,t}$	Dead wood biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)
$DW_{bsl,i,s,t-X_{i,s,t}}$	Dead wood biomass stocks in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
CF	Carbon fraction of dry biomass (t C/t d.m.)
C_f	Combustion factor (dimensionless)

EF_g	Emission factor for gas g (g/kg dry matter burned)
g	1, ...G *gas*; including methane and nitrous oxide

8.2.9 Nitrogen Fertilizer Emissions

Nitrous oxide emissions due to nitrogen fertilizer use in the baseline scenario are conservatively set to zero.

$$Nfert_{bsl,i,s,t} = 0 \tag{19}$$

8.3 Project Removals

8.3.1 Project Scenario Total Stock change

Stock change in the project scenario is estimated for each project plot in sample unit *i* in stratum s in year *t* using Equation (20).[7]

$$\Delta CO2_{wp,i,s,t} = \Delta LAGt_{wp,i,s,t} + \Delta LBGt_{wp,i,s,t} + \Delta LAGnt_{wp,i,s,t} + \Delta LBGnt_{wp,i,s,t} + \Delta DW_{wp,i,s,t} + HWP_{wp,i,s,t} - Bburn_{wp,i,s,t} - Nfert_{wp,i,s,t} \tag{20}$$

Where:

$\Delta CO2_{wp,i,s,t}$	Stock change in the project plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)
$\Delta LAGt_{wp,i,s,t}$	Change in live aboveground tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area per year)
$\Delta LBGt_{wp,i,s,t}$	Change in live belowground tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area per year)
$\Delta LAGnt_{wp,i,s,t}$	Change in live aboveground non-tree biomass stocks in each project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area per year)

[7] Where optional pools are deemed significant, must also account for stock change in these pools in Equation 1.

$\Delta LBGnt_{wp,i,s,t}$	Change in live belowground non-tree biomass stocks in each project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area per year)
$\Delta DW_{wp,i,s,t}$	Change in dead wood biomass stocks in each project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area per year)
$HWP_{wp,i,s,t}$	Harvested wood products remaining stored over 100 years in the project plot in sample unit *i* in stratum s harvested in the monitoring interval ending at time *t* (t CO_2e per unit area per year)
$Bburn_{wp,i,s,t}$	Emissions of methane and nitrous oxide from biomass burning in project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area per year)
$Nfert_{wp,i,s,t}$	Direct and indirect nitrous oxide emissions due to nitrogen fertilizer use in the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area per year)
i =	1, 2, 3,…, *n* sample units
s =	1, 2, 3,…, *S* strata, s = 1 for projects without stratification
t =	1, 2, 3,…, *T* years elapsed since the project start date

8.3.2 Live Aboveground Tree Biomass

$$\Delta LAGt_{wp,i,s,t} = \left(LAGt_{wp,i,s,t} - LAGt_{wp,i,s,t-X_{i,s,t}}\right) \times \left(1/X_{i,s,t}\right) \times \left(\frac{44}{12}\right) \times CF \tag{21}$$

Where:

$\Delta LAGt_{wp,i,s,t}$	Change in live aboveground tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval at time *t* (t CO_2e per unit area per year)
$LAGt_{wp,i,s,t}$	Live aboveground biomass tree stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)
$LAGt_{wp,i,s,t-X_{i,s,t}}$	Live aboveground biomass tree stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)

CF Carbon fraction of dry biomass (t C/t d.m.)

8.3.3 Live Belowground Tree Biomass

$$\Delta LBGt_{wp,i,s,t} = \left(LBGt_{wp,i,s,t} - LBGt_{wp,i,s,t-X_{i,s,t}}\right) \times \left(1/X_{i,s,t}\right) \times \left(\frac{44}{12}\right) \times CF$$

(22)

Where:

$\Delta LBGt_{wp,i,s,t}$ Change in live belowground tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area per year)

$LBGt_{wp,i,s,t}$ Live belowground tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)

$LBGt_{wp,i,s,t-X_{i,s,t}}$ Live belowground tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)

$X_{i,s,t}$ Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)

CF Carbon fraction of dry biomass (t C/t d.m.)

$$LBGt_{wp,i,s,t} = LAGt_{wp,i,s,t} \times R$$

(23)

Where:

$LBGt_{wp,i,s,t}$ Live belowground tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)

$LAGt_{wp,i,s,t}$ Live aboveground tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)

R Root-to-shoot ratio of aboveground tree biomass to belowground tree biomass and aboveground woody non-tree biomass to belowground woody non-tree biomass

$$LBGt_{wp,i,s,t-X_{i,s,t}} = LAGt_{wp,i,s,t-X_{i,s,t}} \times R$$

(24)

Where:

$LBGt_{wp,i,s,t-X_{i,s,t}}$ Live belowground tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)

$LAGt_{wp,i,s,t-X_{i,s,t}}$ Live aboveground tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)

$X_{i,s,t}$ Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)

R Root-to-shoot ratio of aboveground tree biomass to belowground tree biomass and aboveground woody non-tree biomass to belowground woody non-tree biomass

8.3.4 Live Aboveground Woody Non-Tree Biomass

$$\Delta LAGnt_{wp,i,s,t} = \left(LAGnt_{wp,i,s,t} - LAGnt_{wp,i,s,t-X_{i,s,t}}\right) \times \left(1/X_{i,s,t}\right) \times \left(\frac{44}{12}\right) \times CF$$

(25)

Where:

$\Delta LAGnt_{wp,i,s,t}$ Change in live aboveground non-tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area per year)

$LAGnt_{wp,i,s,t}$ Live aboveground woody non-tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)

$LAGnt_{wp,i,s,t-X_{i,s,t}}$ Live aboveground woody non-tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)

$X_{i,s,t}$ Length of measurement interval in the project scenario for sample unit *i* in stratum s ending at time *t* (years)

CF Carbon fraction of dry biomass (t C/t d.m.)

8.3.5 Live Belowground Woody Non-Tree Biomass

$$\Delta LBGnt_{wp,i,s,t} = \left(LBGnt_{wp,i,s,t} - LBGnt_{wp,i,s,t-X_{i,s,t}}\right) \times \left(1/X_{i,s,t}\right) \times \left(\frac{44}{12}\right) \times CF$$

(26)

Where:

$\Delta LBGnt_{wp,i,s,t}$	Change in live belowground non-tree biomass stocks in the project plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)
$LBGnt_{wp,i,s,t}$	Live belowground non-tree biomass stocks in the project plot in sample unit *i* in stratum s in year *t* (t biomass per unit area)
$LBGnt_{wp,i,s,t-X_{i,s,t}}$	Live belowground non-tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{wp,i,s,t}$ (t biomass per unit area)
$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)
CF	Carbon fraction of dry biomass (t C/t d.m.)

$$LBGnt_{wp,i,s,t} = LAGnt_{wp,i,s,t} \times R \tag{27}$$

Where:

$LBGnt_{wp,i,s,t}$	Live belowground non-tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)
$LAGnt_{wp,i,s,t}$	Live aboveground woody non-tree biomass stocks in the project plot in sample unit *i* in stratum *s* in the monitoring interval ending at time *t* (t biomass per unit area)
R	Root-to-shoot ratio of aboveground tree biomass to belowground tree biomass and aboveground woody non-tree biomass to belowground woody non-tree biomass

$$LBGnt_{wp,i,s,t-X_{i,s,t}} = LAGnt_{wp,i,s,t-X_{i,s,t}} \times R \tag{28}$$

Where:

$LBGnt_{wp,i,s,t-X_{i,s,t}}$	Live belowground non-tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
$LAGnt_{wp,i,s,t-X_{i,s,t}}$	Live aboveground woody non-tree biomass stocks in the project plot in sample unit *i* in stratum *s* in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)

$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)
R	Root-to-shoot ratio of aboveground tree biomass to belowground tree biomass and aboveground woody non-tree biomass to belowground woody non-tree biomass

8.3.6 Dead Wood Biomass

$$\varDelta DW_{wp,i,s,t} = \left(DW_{wp,i,s,t} - DW_{wp,i,s,t-X_{i,s,t}}\right) \times \left(1/X_{i,s,t}\right) \times \left(\frac{44}{12}\right) \times CF \tag{29}$$

Where:

$\varDelta DW_{wp,i,s,t}$	Change in dead wood biomass stocks in the project plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)
$DW_{wp,i,s,t}$	Dead wood biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)
$DW_{wp,i,s,t-X_{i,s,t}}$	Dead wood biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)
CF	Carbon fraction of dry biomass (t C/t d.m.)

8.3.7 Harvested Wood Products

Harvested wood product stocks ($HWP_{wp,i,s,t}$) are calculated using Equation (30).

$$HWP_{wp,i,s,t} = \Big(\left(BBremoved_{saw,wt=sfw,wp,i,s,t} \times SF_{saw,wt}\right) + \left(BBremoved_{pulp,wt=sfw,wp,i,s,t} \times SF_{pulp,wt}\right) + \left(BBremoved_{saw,wt=hwd,wp,i,s,t} \times SF_{saw,wt}\right) + \left(BBremoved_{pulp,wt=hwd,wp,i,s,t} \times SF_{pulp,wt}\right) \Big) \times \left(1/X_{i,s,t}\right) \times \left(\frac{44}{12}\right) \times CF \tag{30}$$

Where:

$HWP_{wp,i,s,t}$	Harvested wood products remaining stored for 100 years in the project plot in sample unit *i* in stratum *s*, harvested in the monitoring interval ending at time *t* (t CO_2e per unit area per year)
$BBremoved_{saw,wt,wp,i,s,t}$	Saw log bole biomass stocks in wood type *wt* in commercial species removed in the project plot in sample unit *i* in stratum *s*, harvested in the monitoring interval ending at time *t* (t biomass per unit area)
$BBremoved_{pulp,wt,wp,i,s,t}$	Pulpwood bole biomass stocks in wood type *wt* in commercial species removed in the project plot in sample unit *i* in stratum *s*, harvested in the monitoring interval ending at time *t* (t biomass per unit area)
$SF_{saw,wt}$	Saw log 100-year average storage factor (mass remaining stored in use and landfills over 100 years) for wood type *wt* (dimensionless)
$SF_{pulp,wt}$	Pulpwood 100-year average storage factor (mass remaining stored in use and landfills over 100 years) for wood type *wt* (dimensionless)
wt	Wood type, defined as softwood (sfw) or hardwood (hwd)
$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)
CF	Carbon fraction of dry biomass (t C/t d.m.)

8.3.8 Burning

Where burning occurs in the monitoring interval ending at time *t*, it is assumed that all stock change is subject to burning, and methane and nitrous oxide emissions from fire are included and calculated using Equation (31). Otherwise, $Bburn_{wp,i,s,t}$ is set equal to zero.

$$Bburn_{wp,i,s,t} = (\sum_{g=1}^{G} GWP_g \times ((LAGt_{wp,i,s,t} - LAGt_{wp,i,s,t-X_{wp,i,s,t}}) + (LAGnt_{wp,i,s,t} - LAGnt_{wp,i,s,t-X_{wp,i,s,t}}) + (DW_{wp,i,s,t} - DW_{wp,i,s,t-X_{wp,i,s,t}})) \times \left(\frac{44}{12}\right) \times CF \times C_f \times EF_g \times 10^{-3}) \times \left(1/X_{i,s,t}\right) \tag{31}$$

Where:

$Bburn_{wp,i,s,t}$	Emissions of methane and nitrous oxide in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area per year)
GWP_g	Global warming potential of gas *g* (dimensionless)
$LAGt_{wp,i,s,t}$	Live aboveground tree biomass stocks in the project plot in sample unit *i* in stratum s at time *t* (t biomass per unit area)
$LAGt_{wp,i,s,t-X_{i,s,t}}$	Live aboveground tree biomass stocks in the project plot in sample unit *i* in stratum s at time $t - X_{i,s,t}$ (t biomass per unit area)
$LAGnt_{wp,i,s,t}$	Live aboveground woody non-tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)
$LAGnt_{wp,i,s,t-X_{i,s,t}}$	Live aboveground woody non-tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
$DW_{wp,i,s,t}$	Dead wood biomass stocks in each project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* (t biomass per unit area)
$DW_{wp,i,s,t-X_{i,s,t}}$	Dead wood biomass stocks in each project plot in sample unit *i* in stratum s in the monitoring interval ending at time $t - X_{i,s,t}$ (t biomass per unit area)
CF	Carbon fraction of dry biomass (t C/t d.m.)
C_f	Combustion factor (dimensionless)
EF_g	Emission factor for gas *g* (g/kg dry matter burnt)
g	1, …*G* gas; including methane and nitrous oxide
$X_{i,s,t}$	Length of measurement interval for sample unit *i* in stratum s ending at time *t* (years)

8.3.9 Nitrogen Fertilizer Emissions

Where nitrogen fertilizer is applied due to the project activity, nitrous oxide emissions are calculated using Equation (32):

$$Nfert_{wp,i,s,t} = Nfert_{wp,direct,i,s,t} + Nfert_{wp,indirect,i,s,t} \tag{32}$$

Where:

$Nfert_{wp,i,s,t}$	Direct and indirect nitrous oxide emissions due to nitrogen fertilizer use in the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area)
$Nfert_{wp,direct,i,s,t}$	Direct nitrous oxide emissions due to nitrogen fertilizer use in the project plot for sample unit *i* in stratum s in the monitoring interval ending at *t* (t CO_2e per unit area)
$Nfert_{wp,indirect,i,s,t}$	Indirect nitrous oxide emissions due to nitrogen fertilizer use in the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area)

$$Nfert_{wp,direct,i,s,t} = \left(F_{wp,SN,i,s,t} + F_{wp,ON,i,s,t}\right) \times EF_{Ndirect} \times \frac{44}{28} \times GWP_{N20} \quad (33)$$

$$F_{wp,SN,i,s,t} = M_{wp,SF,i,s,t} \times NC_{wp,SF,i,s,t} \quad (34)$$

$$F_{wp,ON,i,s,t} = M_{wp,OF,i,s,t} \times NC_{wp,OF,i,s,t} \quad (35)$$

Where:

$Nfert_{wp,direct,i,s,t}$	Direct nitrous oxide emissions due to nitrogen fertilizer use in the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area)
$F_{wp,SN,i,s,t}$	Project synthetic N fertilizer applied to the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t N per unit area)
$F_{wp,ON,i,s,t}$	Project organic N fertilizer applied to the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t N per unit area)
$M_{wp,SF,i,s,t}$	Mass of project N-containing synthetic fertilizer applied to the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t fertilizer per unit area)
$M_{wp,OF,i,s,t}$	Mass of project N-containing organic fertilizer applied to the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t fertilizer per unit area)
$NC_{wp,SF,i,s,t}$	N content of project synthetic fertilizer applied to the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t N/t fertilizer)

$NC_{wp,OF,i,s,t}$	N content of project organic fertilizer applied to the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t N/t fertilizer)
$EF_{Ndirect}$	Emission factor for nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments, and crop residues (t N_2O-N/t N applied)
GWP_{N20}	Global warming potential for nitrous oxide (dimensionless)

$$Nfert_{wp,indirect,i,s,t} = Nfert_{wp,volat,i,s,t} + Nfert_{wp,leach,i,s,t}$$

(36)

$$Nfert_{wp,volat,i,s,t} = \left[\left(F_{wp,SN,i,s,t} \times Frac_{gasf}\right) + \left(F_{wp,ON,i,s,t} \times Frac_{gasm}\right)\right] \times EF_{Nvolat} \times \frac{44}{28} \times GWP_{N20}$$

(37)

$$Nfert_{wp,leach,i,s,t} = \left(F_{wp,SN,i,s,t} + F_{wp,ON,i,s,t}\right) \times Frac_{leach} \times EF_{Nleach} \times \frac{44}{28} \times GWP_{N20}$$

(38)

Where:

$Nfert_{wp,indirect,i,s,t}$	Indirect nitrous oxide emissions due to nitrogen fertilizer use in the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area)
$Nfert_{wp,volat,i,s,t}$	Indirect nitrous oxide emissions produced from atmospheric deposition of N volatilized due to nitrogen fertilizer use in the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area)
$Nfert_{wp,leach,i,s,t}$	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 plot for sample unit *i* in stratum s in the monitoring interval ending at time *t*; equal to zero where average annual precipitation is less than potential evapotranspiration, unless the project plot is subject to irrigation (t CO_2e per unit area)
$F_{wp,SN,i,s,t}$	Project synthetic N fertilizer applied to the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t N per unit area)
$F_{wp,ON,i,s,t}$	Project organic N fertilizer applied to the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t* (t N per unit area)

$Frac_{gasf}$	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 or 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])
EF_{Nleach}	Emission factor for nitrous oxide emissions from leaching and runoff (t N_2O-N/t N leached and runoff)
GWP_{N20}	Global warming potential for N_2O (dimensionless)

8.4 Difference in Stock Change in Sample Units

Differences in carbon stock change are calculated for each sample unit *i* in stratum s in year *t.*

$$\Delta CO2_{wp,i,s,t-bsl,i,s,t} = \Delta CO2_{wp,i,s,t} - \Delta CO2_{bsl,i,s,t} \tag{39}$$

Where:

$\Delta CO2_{wp,i,s,t-bsl,i,s,t}$	Difference in carbon stock change between plots in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)
$\Delta CO2_{wp,i,s,t}$	Stock change in the project plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)
$\Delta CO2_{bsl,i,s,t}$	Stock change in the internal control plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)

Removals are averaged across all sample units and strata using Equation (40), where *s = 1* for projects without stratification.

$$\overline{CR_{s,t}} = \frac{1}{n_{s,t}} \times \sum_{i=1}^{n_{s,t}} \Delta CO2_{wp,i,s,t-bsl,i,s,t} \tag{40}$$

Where:

$\overline{CR_{s,t}}$	Mean removals across all sample units in stratum s *in the monitoring interval ending in year t* (t CO_2e per unit area per year)
$\Delta CO2_{wp,i,s,t-bsl,i,s,t}$	Difference in carbon stock change between plots in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)
$n_{s,t}$	Number of sample units in stratum s in year *t*

8.5 Leakage Emissions

Leakage emissions include any emissions or removals of greenhouse gases that occur outside the project boundary but are attributable to the project activity. Leakage includes both activity-shifting leakage (outside the project area but within the project proponent's operations) and market leakage (outside both the project area and the project proponent's operations).

Leakage ($LK_{s,t}$) is calculated using Equation (41):

$$LK_{s,t} = MIN\left(0, A_t \times \left(\left(\frac{1}{n_{s,t}} \times \sum_{i=1}^{n_{s,t}} LTremoved_{wp,i,s,t}\right) - \left(\frac{1}{n_{s,t}} \times \sum_{i=1}^{n_{s,t}} LTremoved_{bsl,i,s,t}\right)\right) \times LF_t\right) \times \left(\frac{44}{12}\right) \times CF \tag{41}$$

Where:

$LK_{s,t}$	Leakage in stratum s in year *t* (t CO_2e)
$LTremoved_{wp,i,s,t}$	Live tree biomass stocks removed in the project plot of sample unit *i* in stratum s that is subject to harvest in the monitoring interval ending at time *t* (t biomass per unit area)
$LTremoved_{bsl,i,s,t}$	Live tree biomass stocks removed in the internal control plot of sample unit *i* in stratum s that is subject to harvest in the monitoring interval ending at time *t* (t biomass per unit area)
LF_t	Leakage factor in year *t* (percent)
$A_{total,t}$	Total implementation area in year *t* (unit area)
$n_{s,t}$	Number of sample units in stratum s in year *t*
CF	Carbon fraction of dry biomass (t C/t d.m.)

8.6 Uncertainty

Uncertainty associated with sampling error is quantified and accounted for using the equations in this section. Uncertainty in area estimation is assumed to be zero and is addressed via using complete (and accurate) GIS boundaries of the project area and applying quality assurance or quality control (QA/QC) procedures specified in the parameter table for A_t. Uncertainty in measurement is assumed to be zero due to the strict QA/QC requirements. Uncertainty in modeling (e.g., allometric equations) is assumed to be zero. Uncertainty deductions are applied independently to each stratum to calculate removals at stratum level, and removals are summed across all strata to calculate the total. Uncertainty ($UNC_{s,t}$) is calculated using Equation (42):

$$UNC_{s,t} = MIN\left(100\%,\ UNC_{sampling,s,t}\right)$$

(42)

Where:

$UNC_{s,t}$	Uncertainty in removals in stratum s in year *t* (percent)
$UNC_{sampling,s,t}$	Uncertainty in removals due to sampling error in stratum s in year *t*, expressed as the half width of the 95% confidence interval as a percentage of the mean (percent)

Sampling error results from measuring only a portion of the project area. Sampling uncertainty is estimated using Equation (43):

$$UNC_{sampling,s,t} = MIN\left(100\%, MAX\left(0,\ T_{\frac{\alpha}{2}} \times \left(\frac{1}{n_{s,t}} \times \hat{\sigma}^2_{CR_{s,t}}\right)^{\frac{1}{2}} \times \left(\frac{1}{\overline{CR_{s,t}}}\right)\right) \times 100\right)$$

(43)

Where:

$UNC_{sampling,s,t}$	Uncertainty in removals due to sampling in strata s in year *t*, expressed as the half width of the 95% confidence interval as a percentage of the mean (percent)
$\hat{\sigma}^2_{CR_{s,t}}$	Sample variance of removals in strata s in year *t* across all sample units in the project
T_{α}	Critical value of a student's t-distribution for significance level α=0.05 (i.e., 1 −α = 95% confidence interval)
$\overline{CR_{s,t}}$	Mean removals across all sample units in strata s in year *t* (t CO_2e per unit area per year)
$n_{s,t}$	Number of sample units in stratum s in year t

Sample variances are calculated using Equation (44):

$$\hat{\sigma}^2_{CR_{s,t}} = \frac{1}{n_{s,t} - 1} \times \sum_{i=1}^{n_{s,t}} [(\Delta CO2_{wp,i,s,t} - \Delta CO2_{bsl,i,s,t}) - CR_{s,t}]^2$$

(44)

Where:

$\hat{\sigma}^2_{CR_t}$	Sample variance of removals in stratum s in year *t* across all sample units in the project
$\Delta CO2_{wp,i,s,t}$	Stock change in the project plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)
$\Delta CO2_{bsl,i,s,t}$	Stock change in the internal control plot in sample unit *i* in stratum s in year *t* (t CO_2e per unit area per year)
$CR_{s,t}$	Net removals from stratum s in year *t* (t CO_2e)
$n_{s,t}$	Number of sample units in stratum s in year *t*

8.6.1 Net Carbon Dioxide Removals

Net removals are calculated at the stratum level in Equation (45) and then summed together in Equation (46) to obtain net removals across all strata. For projects without strata use *s = 1*.

$$CR_{s,t} = \left(\left(A_{s,t} \times \overline{CR_{s,t}}\right) + LK_{s,t}\right) \times (1 - UNC_{s,t})$$

(45)

Where:

$CR_{s,t}$	Net removals in stratum s in year *t* (t CO_2e)
$A_{s,t}$	Implementation area in stratum s in year *t* (unit area)
$\overline{CR_{s,t}}$	Mean removals in stratum s in year *t* across all sample units (t CO_2e per unit area per year)
$LK_{s,t}$	Leakage allocated to removals in stratum s in year *t* (t CO_2e)
$UNC_{s,t}$	Uncertainty in stratum s in year *t* (percent)

$$CR_t = \sum_{s=1}^{S_t} CR_{s,t}$$

(46)

Where:

CR_t	Net removals in year *t* (t CO_2e)
$CR_{s,t}$	Net removals in stratum s in year *t* (t CO_2e)
S_t	Total number of strata in year *t*

8.6.2 Calculation of Verified Carbon Units

To calculate the number of Verified Carbon Units (VCUs) that may be issued, the project proponent must consider the number of buffer credits to be deposited in the AFOLU pooled buffer account. The number of buffer credits that must be deposited is calculated by multiplying the non-permanence risk rating by the net removals (see the most recent applicable version of the *VCS Standard*).

$$BU_{CR,t} = I(CR_t) \times NPR\%$$

(47)

Where:

$I(CR_t)$ = 1 if CR_t > 0 and

$I(CR_t)$ = 0 if $CR_t \leq 0$

$BU_{CR,t}$	Buffer credits to be deducted from removals in year *t* (t CO_2e)
CR_t	Net removals in year *t* (t CO_2e)
$NPR\%$	Overall project non-permanence risk rating converted to a percentage[8]

The number of VCUs that may be issued is calculated using Equation (48):

$$VCU_{CR,t} = CR_t - BU_{CR,t}$$

(48)

Where:

[8] Calculated using the digital AFOLU Non-Permanence Risk Tool in the Verra Project Hub

$VCU_{CR,t}$	Number of Verified Carbon Units that result from project activities leading to removals in year *t* (t CO_2e)
CR_t	Net removals in year *t* (t CO_2e)
$BU_{CR,t}$	Buffer credits to be deducted from removals in year *t* (t CO_2e)

8.7 Ex-Ante Estimation

The project description must include an ex-ante estimation of removals to demonstrate the expected difference between projected performance of the project scenario (project plots) and the baseline scenario (paired internal control plots). The ex-ante estimation must meet the following requirements:

1) Projected changes in biomass must be based on published scientific literature such as growth and yield models constructed with data and parameters that conservatively represent the project activity.
2) Any planned harvest regimes or forest management activities must be incorporated when modeling the project scenario.
3) A minimum uncertainty deduction of 10% must be applied. Project proponents may apply an uncertainty deduction greater than 10% where they wish to be more conservative.

8.7.1 Ex-Ante Estimate of Baseline Removals

The ex-ante estimate of baseline removals is derived using Equation (10), with parameter $\Delta CO2b_{sl,i,s,t}$ obtained from modeled growth and yield values. The output of the growth and yield model must provide an estimate of $\Delta CO2_{bsl,i,s,t}$ in t C.

8.7.2 Ex-Ante Estimate of Project Removals

The ex-ante estimate of project removals is derived as follows:

1) Use Equation (20) with parameter $\Delta CO2_{wp,i,s,t}$ obtained from modeled growth and yield values. The output of the growth and yield model must provide an estimate of $\Delta CO2_{wp,i,s,t}$ in t C.

2) Project proponents may apply treatment effects to $\Delta CO2_{bsl,i,s,t}$ to estimate $\Delta CO2_{wp,i,s,t.}$ The effects must be derived from published studies or validation datasets of prior applications of the treatment within the same region as the project. The treatment effect may be applied as either a multiplicative or additive effect on the baseline (e.g., $\Delta CO2_{bsl,i,s,t}$ × effect = $\Delta CO2_{wp,i,s,t}$ or $\Delta CO2_{bsl,i,s,t}$ + effect = $\Delta CO2_{wp,i,s,t}$).

3) Alternatively, project proponents may use published studies to directly estimate $\Delta CO2_{bsl,i,s,t}$ and $\Delta CO2_{wp,i,s,t}$ for the project (without requiring calculation of additive or multiplicative effects of treatment).

4) In the ex-ante estimate of project removals, project proponents must cite published research justifying that the project intervention is likely to outperform the business-as-usual case.

All other carbon pools (e.g., soil organic carbon) and GHG emission sources may be assumed to be zero, where it is conservative to do so.

9 MONITORING

9.1 Data and Parameters Available at Validation

Data/Parameter	CF
Data unit	t C/t d.m.
Description	Carbon fraction of dry biomass
Equations	8, 9, 12, 13, 16, 17, 18, 21, 22, 25, 26, 29, 30, 31, 41
Source of data	Values from the literature (e.g., IPCC 2006 INV GLs AFOLU Chapter 4 Table 4.3) must be used where available. Otherwise, a default value of 0.47 t C/t d.m. may be used.
Value applied	Values from the literature or default value of 0.47 t C/t d.m
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS Standard
Purpose of data	Calculation of project emissions
Comments	None

Data/Parameter	$SF_{saw,wt}$ $SF_{pulp,wt}$
Data unit	Dimensionless
Description	Saw log 100-year average storage factor (mass remaining stored in use and landfills over 100 years) for wood type *wt* Pulpwood 100-year average storage factor (mass remaining stored in use and landfills over 100 years) for wood type *wt*
Equations	17, 30

<table>
<tr><td>Source of data</td><td>Table 6-A-5 in Hoover, C., Birdsey, R., Goines, B., Lahm, P., Fan, Y., Nowak, D., Prisley, S., Reinhardt, E., Skog, K., Skole, D., Smith, J., Trettin, C., & Woodall, C. (2014). Quantifying greenhouse gas sources and sinks in managed forest systems. In M. Eve, D. Pape, M. Flugge, R. Steele, D. Man, M. Riley-Gilbert, S. Biggar (Eds.), Quantifying greenhouse gas fluxes in agriculture and forestry: Methods for entity-scale inventory. Technical Bulletin Number 1939 (pp. 6.1–6.114). USDA Office of the Chief Economist.[9]</td></tr>
<tr><td>Value applied</td><td>
<table>
<tr><th>U.S. region and timber type</th><th>SF_{saw}</th><th>SF_{pulp}</th></tr>
<tr><td>Northeast softwood</td><td>0.402</td><td>0.136</td></tr>
<tr><td>Northeast hardwood</td><td>0.437</td><td>0.323</td></tr>
<tr><td>North Central softwood</td><td>0.442</td><td>0.138</td></tr>
<tr><td>North Central hardwood</td><td>0.411</td><td>0.370</td></tr>
<tr><td>Pacific Northwest (east) softwood</td><td>0.415</td><td>0.415</td></tr>
<tr><td>Pacific Northwest (west) softwood</td><td>0.511</td><td>0.119</td></tr>
<tr><td>Pacific Northwest (west) hardwood</td><td>0.284</td><td>0.284</td></tr>
<tr><td>Pacific Southwest softwood</td><td>0.444</td><td>0.444</td></tr>
<tr><td>Rocky Mountain softwood</td><td>0.463</td><td>0.463</td></tr>
<tr><td>Southeast softwood</td><td>0.423</td><td>0.191</td></tr>
<tr><td>Southeast hardwood</td><td>0.417</td><td>0.242</td></tr>
<tr><td>South Central softwood</td><td>0.415</td><td>0.215</td></tr>
<tr><td>South Central hardwood</td><td>0.393</td><td>0.229</td></tr>
<tr><td>Other West hardwood</td><td>0.357</td><td>0.357</td></tr>
</table>
</td></tr>
<tr><td>Justification of choice of data or description of</td><td>An explanation of the 100-year average method for harvested wood product carbon storage is given in Hoover et al. (2014) in Section 6.5.1 (p. 6-67 “The intent of this measure is to approximate the average annual climate benefit of withholding carbon from the atmosphere by a certain</td></tr>
</table>

[9] Available at: https://www.fs.usda.gov/treesearch/pubs/46322

measurement methods and procedures applied	amount each year for 100 years as described by a “decay” curve. This average benefit is one that can be credited in the year of harvest. This estimate of average effect is conceptually similar to the measure of the radiative forcing impact of a current year emission of CO_2, CH_4, or other GHG. One ton of CO_2 emissions—in GHG accounting—is equated to the radiative forcing it causes over the 100 years following the emission. The radiative forcing caused in each year is weighted the same over each of the 100 years. We are suggesting the same convention in weighting the carbon storage in wood products equally for each of 100 years.”
Purpose of data	Calculation of baseline and project emissions
Comments	Regions are defined in Hoover et al. (2014). Parameter values above are for application in the United States. For projects outside the United States, derive values using national data where available (consistent with the host country’s National Greenhouse Gas Inventory). Where national data are unavailable, parameters may be derived from other relevant published sources (e.g., Winjum et al. 1998;[10] *2019 IPCC Refinement to the 2006 Guidelines*, Vol. 4 (AFOLU), Ch. 12: Harvested Wood Products.[11]

Data/Parameter	$A_{total,t}$ $A_{s,t}$
Data unit	Unit area
Description	Total implementation area in year *t* (unit area) Implementation area in stratum s in year *t* (unit area)
Equations	3, 4, 41, 45
Source of data	Calculated from GIS data, composed of an aggregate of stands individually delineated at *t* = 0 (or time of inclusion as an instance of a grouped project)
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Delineation of the project area may use a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), or other appropriate data. Any imagery or GIS datasets used must be geo-

[10] Winjum, J. K., S. Brown, and B. Schlamadinger. 1998. “Forest Harvests and Wood Products: Sources and Sinks of Atmospheric Carbon Dioxide.” Forest Science 44 (2): 272–84.

[11] Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch12_HarvestedWoodProducts.pdf

	registered referencing corner points, clear landmarks, or other intersection points.
Purpose of data	Calculation of project emissions
Comments	Area must reflect the actual area treated

Data/Parameter	*GWPg*
Data unit	Dimensionless
Description	Global warming potential of gas *g*
Equations	18, 31, 33, 36, 37, 38
Source of data	As set out in the most recent version of the *VCS Standard*
Value applied	Methane: 25 Nitrous oxide: 298
Justification of choice of data or description of measurement methods and procedures applied	Unless otherwise directed by the VCS Program, the *VCS Standard, v5.0* requires that CH_4 and N_2O must be converted to CO_2e using the 100-year global warming potential derived from the IPCC Fifth Assessment Report (AR5).[12]
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	C_f
Data unit	Dimensionless
Description	Combustion factor
Equations	18, 31

[12] Available at: https://www.ipcc.ch/report/ar5/wg1/

Source of data	Table 3A.1.12 in IPCC (2003). *Good Practice Guidance for Land Use, Land-use Change and Forestry*[13]
Value applied	The combustion 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
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	EF_g
Data unit	g/kg dry matter burned
Description	Emission factor for gas g
Equations	18, 31
Source of data	Table 3A.1.16 in IPCC (2003). *Good Practice Guidance for Land Use, Land-use Change and Forestry*
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
Purpose of data	Calculation of baseline and project emissions
Comments	None

[13] Available at: https://www.ipcc.ch/site/assets/uploads/2018/03/GPG_LULUCF_FULLEN.pdf

Data/Parameter	$EF_{Ndirect}$
Data unit	t N_2O-N/t N applied
Description	Emission factor for nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments, and crop residues
Equations	33
Source of data	Table 11.1 in Chapter 11, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Value applied	0.01
Justification of choice of data or description of measurement methods and procedures applied	See source of data
Purpose of data	Calculation of baseline and project emissions
Comments	None

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	37
Source of data	Table 11.3 in Chapter 11, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Value applied	0.11
Justification of choice of data or description of	See source of data

measurement methods and procedures applied	
Purpose of data	Calculation of baseline and 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	37
Source of data	Table 11.3 in Chapter 11, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Value applied	0.21
Justification of choice of data or description of measurement methods and procedures applied	See source of data
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	EF_{Nvolat}
Data unit	t N_2O-N/(t NH_3-N + NO_x-N volatilized)
Description	Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces
Equations	37

Source of data	Table 11.3 in Chapter 11, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Value applied	0.01
Justification of choice of data or description of measurement methods and procedures applied	See source of data
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	$Frac_{leach}$
Data unit	Dimensionless
Description	Fraction of N (synthetic or organic) added to soils that is lost through leaching and runoff, in regions where leaching and runoff occurs
Equations	38
Source of data	Table 11.3 in Chapter 11, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Value applied	0.24
Justification of choice of data or description of measurement methods and procedures applied	See source of data
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	EF_{Nleach}
Data unit	t N_2O-N/t N leached and runoff
Description	Emission factor for nitrous oxide emissions from leaching and runoff
Equations	38
Source of data	Table 11.3 in Chapter 11, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Value applied	0.011
Justification of choice of data or description of measurement methods and procedures applied	See source of data
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	R
Data unit	t root d.m./t shoot d.m.
Description	Root-to-shoot ratio of aboveground tree biomass to belowground tree biomass and aboveground woody non-tree biomass to belowground woody non-tree biomass
Equations	10, 11, 14, 15, 23, 24, 27, 28
Source of data	Table 4.4 in Chapter 4, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Justification of choice of data or description of	Where the relevant NFI does not provide procedures for estimating belowground biomass, project proponents must apply globally recognized root-to-shoot ratios (R:S) consistent with the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.[14] In

[14] Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

measurement methods and procedures applied	such cases, belowground biomass must be calculated by multiplying estimated aboveground biomass by the appropriate R:S value for the corresponding forest type, ecological zone, and management condition (see Updated Table 4.4 in Chapter 4, Vol. 4 of IPCC (2019)[15]). The selected ratios must reflect species and stand characteristics to the extent possible, and their application must be transparently documented to ensure consistency, reproducibility, and alignment with international good practice. Root to shoot ratio values from IPCC (2019) must be followed unless there are published refinements to these ratios, such as in the following peer-reviewed publications: Huang, Y., Ciais, P., Santoro, M., Makowski, D., Chave, J., Schepaschenko, D., Abramoff, R.Z., Goll, D.S., Yang, H., Chen, Y. and Wei, W., 2021. A global map of root biomass across the world's forests. *Earth System Science Data*, 13(9), pp.4263-4274. https://doi.org/10.5194/essd-13-4263-2021 Ye, J., Yue, C., Hu, Y. and Ma, H., 2021. Spatial patterns of global-scale forest root-shoot ratio and their controlling factors. *Science of the Total Environment*, 800, p.149251. https://doi.org/10.1016/j.scitotenv.2021.149251 Ma, H., Mo, L., Crowther, T.W., Maynard, D.S., van den Hoogen, J., Stocker, B.D., Terrer, C. and Zohner, C.M., 2021. The global distribution and environmental drivers of aboveground versus belowground plant biomass. *Nature Ecology & Evolution*, 5(8), pp.1110-1122. https://doi.org/10.1038/s41559-021-01485-1
Purpose of data	Calculation of belowground tree biomass
Comments	None

9.2 Data and Parameters Monitored

Data/Parameter	$LAGt_{bsl,i,s,t}$ $LAGt_{wp,i,s,t}$
Data unit	t biomass per unit area
Description	Live aboveground tree biomass stocks in the internal control plot in sample unit *i* in stratum *s* in the monitoring interval ending at time *t*

[15] Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch04_Forest%20Land.pdf

	Live aboveground tree biomass stocks in the project plot in sample unit *i* in stratum s in the monitoring interval ending at time *t*
Equations	8, 10, 11, 18, 21, 23, 24, 31
Source of data	Measured in project and internal control plots
Description of measurement methods and procedures to be applied	Live aboveground tree biomass is measured via plot-based sampling. Acknowledging the wide range of valid approaches, and that relative efficiency and robustness are circumstance-specific, procedures for sampling, measurement, and estimation 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. Sample measurements must: ● be demonstrated to be unbiased and derived from representative sampling. ● ensure measurement accuracy through adherence to best practices and quality assurance and quality control (QA/QC) procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection). ● apply fixed diameter at breast height (dbh) and any other size thresholds. Aboveground biomass of each sampled tree is estimated using published allometric equations (in the United States, using Westfall et al. 2024[16] or stem volume-referenced component ratio methods per Woodall et al. 2011[17], in the tropics, using Chave et al. 2014[18]) applied to one or more measured tree attributes, minimally including dbh. For component ratio methods in the United States, stem volumes must be estimated by applying published volume equations (using equations included in the US Forest Service National Volume Estimator Library (NVEL)[19]) specific to species, genus, or family, in descending order of preference, as available. For wood density estimates, use the Global Wood Density database[20] [21] in the following mandatory hierarchy: species-specific, then genus-specific,

[16] Westfall, James A., et al. "A national-scale tree volume, biomass, and carbon modeling system for the United States." *Gen. Tech. Rep. WO-104. Washington, DC: US Department of Agriculture, Forest Service.* 104 (2024). https://doi.org/10.2737/WO-GTR-104

[17] Woodall, C. W., Heath, L. S., Domke, G. M., & Nichols, M. C. (2011). *Methods and equations for estimating aboveground volume, biomass, and carbon for trees in the US forest inventory, 2010*. U.S. Department of Agriculture, Forest Service, Northeastern Research Station. https://doi.org/10.2737/NRS-GTR-88

[18] Chave et al. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees; Global Change Biology 20 (10): 3177-3190.

[19] Available at: https://www.fs.fed.us/forestmanagement/products/measurement/volume/nvel/index.php

[20] Zanne AE, Lopez-Gonzalez G, Coomes DA, Ilic J, Jansen S, Lewis SL, Miller RB, Swenson NG, Wiemann MC, Chave J (2009) Data from: Towards a worldwide wood economics spectrum. Dryad Digital Repository. doi:10.5061/dryad.234

[21] Zanne, A.E. (2009) Towards a worldwide wood economics spectrum. Ecology Letters, 12, 351–366

	then family-specific, as available, then use the stand-level average wood density if species, genus, and family are not available. The same estimation equations, volume models, and wood density values must be used consistently for both baseline and project calculations. Allometric equations may be developed by the project proponent. Where this approach is applied, the equations must meet the appropriateness requirements set out in the CDM tool *Demonstrating Appropriateness of Allometric Equations for Estimation of Aboveground Tree Biomass in A/R CDM Project Activities.* Species-, genus- and family-specific allometric equations may not always be available and may be difficult to apply with certainty in the typically species-rich forests of the humid tropics.[22] Hence, equations developed for regional forest types may be used, provided that their accuracy has been validated with direct site-specific data following guidance given below. Forest-type specific equations must not be used in combination with species-specific equations (i.e., the same equation must be used for all tree species[23]). For extratropical projects, the *allodb* R package includes a database from 701 woody species identified at 24 large Forest Global Earth Observatory (ForestGEO) forest dynamics plots representing a wide diversity of extratropical forests. See more in Gonzalez-Akre et al. (2021).[24] Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly measured in the field or using airborne LiDAR by applying established best practices, such as those found in the following publications: Kershaw Jr, J. A., Ducey, M. J., Beers, T. W., & Husch, B. (2016). *Forest mensuration*. John Wiley & Sons. Avery, T. E., & Burkhart, H. E. (2015). *Forest measurements*. Waveland Press. U.S. Forest Service Department of Agriculture (2019). *Field data collection procedures for Phase 2 plots*. Forest Inventory and Analysis National Core Field Guide.[25]

[22] Continuously updated database for allometric equations can be found from FAO's GlobAllomeTree database http://www.globallometree.org/. See Henry et al. (2013) iForest - Biogeosciences and Forestry, Volume 6, Issue 6, Pages 326-330 (2013)

[23] Note that forest type specific and pantropical equations will typically not include palm species or hollow-stem species (e.g. *Cecropia*) and so specific equations for these growth forms will be needed.

[24] https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.13756

[25] https://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2019/core_ver9-0_10_2019_final_rev_2_10_2020.pdf

	Ganz, S., Kaber, Y., & Adler, P. 2019. Measuring Tree Height with Remote Sensing—A Comparison of Photogrammetric and LiDAR Data with Different Field Measurements. *Forests*. 10(8), 694; doi:10.3390/f10080694. [26] Silva, M. *et al*. 2018. Airborne laser scanning for terrain modeling in the Amazon forest. *Acta Amazonica*. Vol. 48(4) 271 - 279. http://dx.doi.org/10.1590/1809-4392201800132 [27] White, J, C., Wulder, M, A., Varhola, A, Vastaranta, M., Coops, N, C., Cook, B, D., Pitt, D., & Woods, M. 2013. A best practices guide for generating forest inventory attributes from airborne laser scanning data using an area-based approach. *The Forestry Chronicle*. 89(06): 722-723. https://doi.org/10.5558/tfc2013-132[28] Measurement protocols must 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	Initial measurement at time t = 0 and remeasured every five years or more frequently in the project and baseline scenarios
QA/QC procedures to be applied	To be determined by the project proponent and outlined in standard operating procedures governing field data collection.
Purpose of data	Calculation of project and baseline emissions
Calculation method	N/A
Comments	None

Data/Parameter	$LAGnt_{bsl,i,s,t}$ $LAGnt_{wp,i,s,t}$
Data unit	t biomass per unit area
Description	Live aboveground woody non-tree biomass stocks in the internal control plot in sample unit i in stratum s in the monitoring interval ending at time t

[26] https://pdfs.semanticscholar.org/f019/9ef3c80449dcd26709c11fead19bb80b3aa0.pdf

[27] https://www.scielo.br/j/aa/a/dY8sWg6p6PTxZdmXjqRKZbr/?lang=en&format=pdf

[28] https://pubs.cif-ifc.org/doi/10.5558/tfc2013-132

	Live aboveground woody non-tree biomass stocks in the project plot in sample unit *i* in stratum *s* in the monitoring interval ending at time *t*
Equations	12, 14, 15, 18, 25, 27, 28, 31
Source of data	Measured in project and internal control plots
Description of measurement methods and procedures to be applied	Live aboveground woody non-tree biomass is measured via plot-based sampling. Acknowledging the wide range of valid approaches, and that relative efficiency and robustness are circumstance-specific, procedures for sampling, measurement, and estimation are not specified in the methodology and may be selected by project proponents based on capacity and appropriateness. Given the density of this plant group, aboveground biomass is calculated based on stem counts of woody plants in estimated diameter size classes. For lianas, this should follow established best practice[29] modified for carbon accounting. Stratification may be employed to improve precision but is not required. Sample measurements must: • be demonstrated to be unbiased and derived from representative sampling. • ensure accuracy of measurements 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). • apply fixed diameter at breast height (dbh) and any other size thresholds. Aboveground biomass for woody non-tree plants (e.g., lianas) is estimated using the most appropriate available published allometries. For example, various liana allometries are mentioned in Mackintosh et al 2025[30] including a pantropical allometry by Schnitzer et al. 2006.[31] The pantropical allometric equation may be used for lianas in the absence of better performing allometries that are specific to project region and other factors such as forest condition. Plant parameters (e.g., diameter for lianas) incorporated as independent variables in allometric equations must be measured in the field. Measurement protocols must be detailed in standard operating procedures. Parameter tables for all attributes (e.g., dbh) incorporated as

[29] Schnitzer, S., Rutishauser, S., & Aguilar, S. (2008). Supplemental protocol for liana censuses. Forest Ecology and Management, 255 1044-1049.

[30] Mackintosh, E. J., C. E. Waite, M. Pfeifer, F. E. Putz, and A. R. Marshall. 2025. “Estimating Above-Ground Liana Biomass in Disturbed Australian Tropical Forests.” Austral Ecology 50, no. 6: e70050.

[31] Schnitzer, S., DeWalt, S., & Chave., J. (2006). Censusing and Measuring Lianas: A Quantitative Comparison of the Common Methods. *Biotropica, 38(5): 581-591.*

	independent variables in allometric equations must be included in the project description under Data and Parameters Monitored.
Frequency of monitoring/recording	Initial measurement at time t = 0 and remeasured every five years or more frequently in the project and baseline scenarios
QA/QC procedures to be applied	To be determined by the project proponent and outlined in standard operating procedures governing field data collection
Purpose of data	Calculation of project and baseline emissions
Calculation method	N/A
Comments	None

Data/Parameter	$DW_{bsl,i,s,t}$ $DW_{wp,i,s,t}$
Data unit	t biomass per unit area
Description	Dead wood biomass stocks in the internal control plot in sample unit *i* in stratum *s* in the monitoring interval ending at time *t* Dead wood biomass stocks in the project plot in sample unit *i* in stratum *s* in the monitoring interval ending at time *t*
Equations	16, 18, 29, 31
Source of data	Measured on project and internal control plots
Description of measurement methods and procedures to be applied	Standing dead wood is sampled via plot-based forest inventory method. Specific sample designs or intensities, and measurement 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. Sample measurements must: ● be demonstrated to be unbiased and derived from representative sampling. ● ensure accuracy of measurements 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). ● apply fixed size thresholds.

	Aboveground biomass of each standing dead tree is estimated using published allometric equations (in the United States, using Jenkins et al. 2003 or stem volume-referenced component ratio methods per Woodall et al. 2011, in the tropics, using Chave et al. 2014) applied to one or more measured tree attributes, minimally including dbh and remaining stem height. Standing dead wood is restricted here to aboveground stem (bole) biomass. For component ratio methods in the United States, stem volumes must be estimated by applying published volume equations (using equations included in the US Forest Service National Volume Estimator Library (NVEL)) specific to species, genus, or family, in descending order of preference, as available. For wood density estimates, use the Global Wood Density database in the following mandatory hierarchy: species-specific, then genus-specific, then family-specific, as available, then use the stand-level average wood density if species, genus, and family are not available. The same estimation equations, volume models, and wood density values must be used consistently for both baseline and project calculations. 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 the following publications: Kershaw Jr, J. A., Ducey, M. J., Beers, T. W., & Husch, B. (2016). *Forest mensuration*. John Wiley & Sons. Avery, T. E., & Burkhart, H.E. (2015). *Forest measurements*. Waveland Press. U.S. Forest Service Department of Agriculture (2019). *Field data collection procedures for Phase 2 plots*. Forest Inventory and Analysis National Core Field Guide.[32] Measurement protocols must 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	Initial measurement at time t = 0 and remeasured every five years or more frequently in the project and baseline scenarios
QA/QC procedures to be applied	To be determined by the project proponent and outlined in standard operating procedures governing field data collection
Purpose of data	Calculation of project and baseline emissions

[32] Available at: https://research.fs.usda.gov/sites/default/files/2024-02/wo-v9-3_sep2023_fg_nfi_natl.pdf

Calculation method	N/A
Comments	None

Data/Parameter	$BBremoved_{saw,wt,bsl,i,s,t}$ $BBremoved_{saw,wt,wp,i,s,t}$
Data unit	t biomass per unit area
Description	Saw log bole biomass stocks in wood type *wt* in commercial species removed from the internal control plot in sample unit *i* in stratum *s* harvested in the monitoring interval ending at time *t* Saw log bole biomass stocks in wood type *wt* in commercial species removed in the project plot in sample unit *i* in stratum *s* harvested in the monitoring interval ending at time *t*
Equations	17, 30, A4, A5, A7, A8
Source of data	Field measurements from project and internal control plots subject to harvest in the monitoring interval ending at time *t*
Description of measurement methods and procedures to be applied	For projects in the United States, saw logs are distinguished from pulpwood on the basis of dbh: a) Softwood saw logs are from trees with dbh of at least 22.9 cm (9 in). b) Hardwood saw logs are from trees with dbh of at least 27.9 cm (11 in). Saw log bole biomass is estimated for saw log-sized stems cut and removed in the monitoring interval ending at time *t,* from the most recent pre-harvest measurements preceding time *t* in sample unit *i* in stratum *s* (i.e., $LAGt_{bsl,i,s,t-X_{i,s,t}}$), via either of the following two approaches: **Approach 1 – Estimate bole volume and apply wood density** Bole biomass is estimated by applying published volume equations (e.g., those included in the US Forest Service National Volume Estimator Library (NVEL)[33]) and wood densities (specific to species, genus, or family, in descending order of preference, as available). Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly measured in the field,

[33] Available at: https://www.fs.usda.gov/managing-land/forest-management/products/measurement/volume-estimation

	or using airborne LiDAR by applying established best practices, such as those found in the following publications: Kershaw Jr, J. A., Ducey, M. J., Beers, T. W., & Husch, B. (2016). *Forest mensuration*. John Wiley & Sons. Avery, T. E., & Burkhart, H. E. (2015). *Forest measurements*. Waveland Press. U.S. Forest Service Department of Agriculture (2019). *Field data collection procedures for Phase 2 plots*. Forest Inventory and Analysis National Core Field Guide. [34] Ganz, S., Kaber, Y., & Adler, P. 2019. Measuring Tree Height with Remote Sensing—A Comparison of Photogrammetric and LiDAR Data with Different Field Measurements. *Forests*. 10(8), 694; doi:10.3390/f10080694. [35] Silva, M. *et al*. 2018. Airborne laser scanning for terrain modeling in the Amazon forest. *Acta Amazonica*. Vol. 48(4) 271 - 279. http://dx.doi.org/10.1590/1809-4392201800132 [36] White, J, C., Wulder, M, A., Varhola, A, Vastaranta, M., Coops, N, C., Cook, B, D., Pitt, D., & Woods, M. 2013. A best practices guide for generating forest inventory attributes from airborne laser scanning data using an area-based approach. *The Forestry Chronicle*. 89(06): 722-723. https://doi.org/10.5558/tfc2013-132[37] Measurement protocols must 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. **Approach 2 – Estimate aboveground biomass and apply stem component ratio** Bole biomass is estimated by applying a published stem component ratio to total aboveground biomass estimated using a published allometric

[34] Available at: https://research.fs.usda.gov/sites/default/files/2024-02/wo-v9-3_sep2023_fg_nfi_natl.pdf

[35] https://www.mdpi.com/1999-4907/10/8/694

[36] https://www.scielo.br/j/aa/a/dY8sWg6p6PTxZdmXjqRKZbr/?lang=en&format=pdf

[37] https://pubs.cif-ifc.org/doi/10.5558/tfc2013-132

	equation (e.g., in the US, using Jenkins et al. 2003[38] for stem component ratios and total aboveground biomass equations). Note that these estimates are restricted to commercial species. In the United States, commercial species are defined as those not from species groups 23, 43, and 48 (see FIA Database User Guide Appendix E[39]). For projects outside the United States, the classification and estimation of saw logs must follow the definitions, dimensional thresholds, and measurement approaches established by the relevant National Forest Inventory (NFI). Where applicable, project proponents must apply the NFI's published criteria for distinguishing saw logs from pulpwood, including any species-specific or forest-type–specific diameter thresholds, merchantability rules, or log-grade specifications. Biomass for each component must be derived using the NFI's prescribed estimation methods — whether volume equations, wood density values, or component-ratio models — and all measurement protocols, volume definitions, and conversion factors must be documented in project-specific standard operating procedures. Where the NFI does not provide explicit guidance for certain species or size classes, project proponents may apply internationally recognized mensuration practices and peer-reviewed equations, provided these are transparently documented and applied consistently across both project and baseline scenarios.
Frequency of monitoring/recording	Initial measurement at time t = 0 and remeasured every five years or more frequently in the project and baseline scenarios
QA/QC procedures to be applied	To be determined by the project proponent and outlined in standard operating procedures governing field data collection
Purpose of data	Calculation of project and baseline emissions
Calculation method	N/A
Comments	None

Data/Parameter	$BBremoved_{pulp,wt,bsl,i,s,t}$

[38] Jenkins, J. C., Chojnacky, D. C., Heath, L. S., & Birdsey, R. A. (2003). National-scale biomass estimators for United States tree species. *Forest Science*, *49*(1), 12–35.

[39] Available at: https://research.fs.usda.gov/sites/default/files/2024-12/wo-v9-3_dec2024_ug_fiadb_database_description_nfi.pdf

	$BBremoved_{pulp,wt,wp,i,s,t}$
Data unit	t biomass per unit area
Description	Pulpwood bole biomass stocks in wood type *wt* in commercial species removed from the internal control plot in sample unit *i* in stratum s harvested in the monitoring interval ending at time *t* Pulpwood bole biomass stocks in wood type *wt* in commercial species removed in the project plot in sample unit *i* in stratum s harvested in the monitoring interval ending at time *t*
Equations	17, 30, A4, A5, A7, A8
Source of data	Field measurements from project and internal control plots subject to harvest in the monitoring interval ending at time *t*
Description of measurement methods and procedures to be applied	Pulpwood logs are distinguished from saw logs on the basis of diameter at breast height: a) Softwood pulpwood is from trees with 12.7 to 22.8 cm (5.0 to 8.9 in) dbh b) Hardwood pulpwood is from trees with 12.7 to 27.8 cm (5.0 to 10.9 in) dbh Pulpwood bole biomass is estimated for pulpwood-sized stems cut and removed in the monitoring interval ending at time *t,* from the most recent pre-harvest measurements (i.e., $LAGt_{bsl,i,s,t-X_{i,s,t}}$), via either of the following two approaches: **Approach 1 – Estimate bole volume and apply wood density** Bole biomass is estimated by applying published volume equations (e.g., equations included in the US Forest Service National Volume Estimator Library (NVEL)[40]) and wood densities (specific to species, genus, or family, in descending order of preference, as available). Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly measured in the field, or using airborne LiDAR by applying established best practices, such as those found in the following publications: Kershaw Jr, J. A., Ducey, M. J., Beers, T. W., & Husch, B. (2016). *Forest mensuration*. John Wiley & Sons. Avery, T. E., & Burkhart, H. E. (2015). *Forest measurements*. Waveland Press.

[40] Available at: https://www.fs.usda.gov/managing-land/forest-management/products/measurement/volume-estimation

	U.S. Forest Service Department of Agriculture (2019). *Field data collection procedures for Phase 2 plots*. Forest Inventory and Analysis National Core Field Guide[41] Ganz, S., Kaber, Y., & Adler, P. 2019. Measuring Tree Height with Remote Sensing—A Comparison of Photogrammetric and LiDAR Data with Different Field Measurements. *Forests*. 10(8), 694; doi:10.3390/f10080694. [42] Silva, M. *et al*. 2018. Airborne laser scanning for terrain modeling in the Amazon forest. *Acta Amazonica*. Vol. 48(4) 271 - 279. http://dx.doi.org/10.1590/1809-4392201800132 [43] White, J, C., Wulder, M, A., Varhola, A, Vastaranta, M., Coops, N, C., Cook, B, D., Pitt, D., & Woods, M. 2013. A best practices guide for generating forest inventory attributes from airborne laser scanning data using an area-based approach. *The Forestry Chronicle*. 89(06): 722-723. https://doi.org/10.5558/tfc2013-132[44] Measurement protocols must 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. **Approach 2 – Estimate aboveground biomass and apply stem component ratio** Bole biomass is estimated by applying a published stem component ratio to total aboveground biomass estimated using a published allometric equation (e.g., in the US using Jenkins et al. 2003[45] for stem component ratios and total aboveground biomass equations). Note that these estimates are restricted to commercial species. In the United States, commercial species are defined as those not from species groups 23, 43, and 48 (see FIA Database User Guide Appendix E[46]).

[41] Available at: https://research.fs.usda.gov/sites/default/files/2024-12/wo-v9-3_dec2024_ug_fiadb_database_description_nfi.pdf

[42] https://www.mdpi.com/1999-4907/10/8/694

[43] https://www.scielo.br/j/aa/a/dY8sWg6p6PTxZdmXjqRKZbr/?lang=en&format=pdf

[44] https://pubs.cif-ifc.org/doi/10.5558/tfc2013-132

[45] Jenkins, J. C., Chojnacky, D. C., Heath, L. S., & Birdsey, R. A. (2003). National-scale biomass estimators for United States tree species. *Forest Science*, *49*(1), 12–35.

[46] Available at: https://research.fs.usda.gov/sites/default/files/2024-12/wo-v9-3_dec2024_ug_fiadb_database_description_nfi.pdf

Frequency of monitoring/recording	Initial measurement at time *t* = 0 and remeasured every five years or more frequently in the project and baseline scenarios
QA/QC procedures to be applied	To be determined by the project proponent and outlined in standard operating procedures governing field data collection
Purpose of data	Calculation of project and baseline emissions
Calculation method	N/A
Comments	None

Data/Parameter	$M_{wp,SF,i,s,t}$
Data unit	t fertilizer per unit area
Description	Mass of project N-containing synthetic fertilizer applied to the project plot for sample unit *i* in stratum s in the monitoring interval ending at time *t*
Equations	34
Source of data	Application records, substantiated with one or more forms of documented evidence pertaining to the selected sample unit and relevant monitoring period (e.g., management logs, receipts, or invoices)
Description of measurement methods and procedures to be applied	Information is monitored via direct consultation with the local land manager
Frequency of monitoring/recording	Initial measurement at time *t* = 0 and remeasured every five years or more frequently in the project and baseline scenarios
QA/QC procedures to be applied	See “Source of data”
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	None

Data/Parameter	$NC_{wp,SF,i,s,t}$
Data unit	t N/t fertilizer
Description	N content of project synthetic fertilizer applied to the project plot for sample unit *i* in stratum *s* in the monitoring interval ending at time *t*
Equations	34

Source of data	N content is determined following fertilizer manufacturer's specifications.
Description of measurement methods and procedures to be applied	Not directly measured
Frequency of monitoring/recording	Initial measurement at time *t* = 0 and remeasured every five years or more frequently in the project and baseline scenarios
QA/QC procedures to be applied	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 and relevant monitoring period (e.g., management logs, receipts, or invoices)
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	None

Data/Parameter	$M_{wp,OF,i,s,t}$
Data unit	t fertilizer per unit area
Description	Mass of project N-containing organic fertilizer applied to the project plot for sample unit *i* in stratum *s* in the monitoring interval ending at time *t*
Equations	35
Source of data	N content is determined following fertilizer manufacturer's specifications.
Description of measurement methods and procedures to be applied	Application records, substantiated with one or more forms of documented evidence pertaining to the selected sample unit and relevant monitoring period (e.g., management logs, receipts, or invoices)
Frequency of monitoring/recording	Initial measurement at time *t*=0 and to be re-measured every 5 years or more frequently in the project and baseline scenarios
QA/QC procedures to be applied	See "Source of data"
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	None

Data/Parameter	$NC_{wp,OF,i,s,t}$

Data unit	t N/t fertilizer
Description	N content of project organic fertilizer applied to the project plot for sample unit i in stratum s in the monitoring interval ending at time t
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) cited in US Environmental Protection Agency (2011). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009. EPA 430-R-11-005*.
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Initial measurement at time t = 0 and remeasured every five years or more frequently in the project and baseline scenarios
QA/QC procedures to be applied	Data referenced must be published or peer reviewed
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	None

9.3 Description of the Monitoring Plan

Monitoring is conducted for both the baseline and project scenarios. Monitoring employs a quasi-experimental design where carbon stock change is directly monitored in paired permanent project plots and internal control plots. Monitored stock parameters are collected and recorded at the sample unit (pair) scale, and carbon removals are estimated independently for each sample unit.

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) A description of each monitoring task to be undertaken, and the technical requirements therein

2) Definition of the accounting boundary

3) Parameters to be measured, including parameter tables for all directly measured tree attributes (e.g., diameter at breast height, total height) incorporated as independent variables in allometric equations

4) Data to be collected and data collection techniques, documented in a standard operating procedure for field data collection. Sample designs must be specified (clearly delineating the sample population spatially, and justifying sampling intensities, selection of sample units, and sampling stages, where applicable) and un-biased estimators of population parameters identified, which will be applied in calculations.

5) Anticipated frequency of monitoring

6) Quality assurance and quality control (QA/QC) procedures to ensure accurate data collection and screen for, and where necessary, correct anomalous values, ensure completeness, perform independent checks on analysis results, and other safeguards as appropriate

7) Data archiving procedures, including procedures for any anticipated updates to electronic file formats. All data collected as a part of the monitoring process, including QA/QC data, must be archived electronically and kept for at least two years after the end of the last project crediting period.

8) Roles, responsibilities, and capacity of monitoring team and management.

As part of monitoring, project proponents must describe the environmental safeguard mitigation activities that have been implemented during the monitoring period. This must be supported by verifiable documentation, such as management records, field reports, or remote sensing data.

Permanent sample plots (constituting project sample units)
Permanent plot measurements must be archived, and all trees assigned unique identification numbers. Individual trees on permanent plots must be marked in the field (e.g., painted or tagged) and stems mapped with azimuth and distance from plot center recorded.

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APPENDIX 1: RANDOMIZED CONTROL TRIAL SAMPLING DESIGN AND INTEGRITY BENCHMARKING

A1.1 Introduction

This appendix establishes the protocol for the selection, placement, and maintenance of project plots and associated internal control plots within the project implementation area. It further defines the integrity benchmark, which is conceptually aligned with the performance benchmark framework in *VCS* methodology *VM0047 Afforestation, Reforestation, and Revegetation*. The integrity benchmark is designed to assess whether internal control plots are representative of prevailing landscape-level conditions and are not subject to systematic bias. The external benchmark plots and internal control plots are compared using remote sensing observations. This approach ensures that internal control plots exhibit performance consistent with comparable forest stands in the surrounding landscape, thereby supporting the credibility of baseline estimation and treatment effect attribution. All project strata must be represented by project, control, and external benchmark plots.

A1.2 Internal Control and Project Plot Design

A1.2.1 Guarding Against Control Plot Tampering

Project proponents must not tamper with internal control plots or otherwise influence the change in biomass or growing conditions of internal control plots except through business-as-usual practices[47].

As a condition of validation, project proponents and participating landowners must sign a written attestation affirming that:

a. they have not influenced, and will not influence, the biomass or growing conditions of internal control plots beyond business-as-usual practices
b. they understand that any such tampering or undue influence may result in invalidation of project credits and/or removal from the program.

The signed attestation(s) must be submitted to the validator as part of the validation documentation and renewed at each subsequent verification event.

[47] Reducing carbon removals in internal control plots would artificially increase the difference in removals between the internal control and project plots, attributing more additional removals to the project activity than have actually been achieved.

A1.2.2 Procedure for Establishing Internal Control and Project Plots

Internal control plots are established within the project implementation area to represent the counterfactual scenario where the project activity has not been implemented.

Internal control and project plots must be established using the following protocol implemented with GIS tools:

A. Stratify project area. Stratification must remain consistent for the duration of the project. For project instances implementing project activities over multiple years, stratification must include project activity year.[48]

B. Define a grid across the project area for each strata. Remove any grid cells that intersect the project boundary such that any portion of the cell lies outside the project area. The remaining grid cells represent centrally located candidate internal control plot locations and project plot locations. Each internal control plot and equally sized paired project plot must be at least 30 m × 30 m and the grid size should be larger than this depending on the treatment exclusion zone required for treatment.

C. Note — A large plot size is used here to ensure that multiple pixels from remotely sensed data fit inside each control plot location. These pixels are used to establish internal control plot validity in the integrity benchmark step described below.

D. Determine the required number of sample units and/or number of trees within each plot, based on a power analysis. All project strata must be represented by project, internal control, and external benchmark plots:

    a. Simple power analysis (Section A1.2.3) must be applied to determine the number of sample units required within each stratum.

    b. Adequate representation of sample units is required to ensure statistically robust estimation of baseline carbon dynamics. Project proponents must install a sufficient number of sample units within each project stratum to achieve a minimum statistical power of 0.80 ($1 - \beta = 0.80$) at $\alpha = 0.05$ (one-tailed) for detecting the carbon stock change between project and baseline scenarios, using documented variance estimates from prior inventory data, peer-reviewed literature, or a pilot sample.

E. Choose one of the following paired analysis approaches to assign plot locations:

    a. Neighbor pair analysis:

        i) Randomly select grid cells to equal the number of sample units required in (A) above.

[48] This ensures that stratum-level removals, which are calculated based on area within each stratum, do not include areas within a stratum that have not yet received enhanced sequestration treatment.

ii) Randomly pick an adjoining cell to each candidate plot cell.

iii) Randomly assign each cell in an adjoining pair to project plot or internal control plot. There must be a 1:1 ratio between project and control plots.

b. Matched pair analysis:

i) Randomly select grid cells to equal the number of sample units required in (A) above.

ii) For each randomly selected grid cell:

1. determine matched grid cell(s) within the remaining unselected grid cells based on covariates (Table A1) and matching statistics such as propensity scores or k-nearest neighbor methods. Matched grid cells must meet a minimum matching threshold or be the most closely matched grid cells in the pool. Where more than one grid cell matches, choose the grid cell with the highest degree of similarity (e.g., lowest Mahalanobis distance).

2. remove matched grid cells from pool and repeat previous steps.

iii) Randomly assign one of a matched pair of grid cells to project plot and the other to internal control plot. There should be a 1:1 ratio between project plots and internal control plots.

iv) Repeat (iii) above for each remaining randomly selected pair of grid cells.

F. Construct the treatment exclusion zones in the internal control plots within all sample units. A surrounding treatment exclusion zone must be established around each internal control plot and is not eligible for crediting (Figure 1).

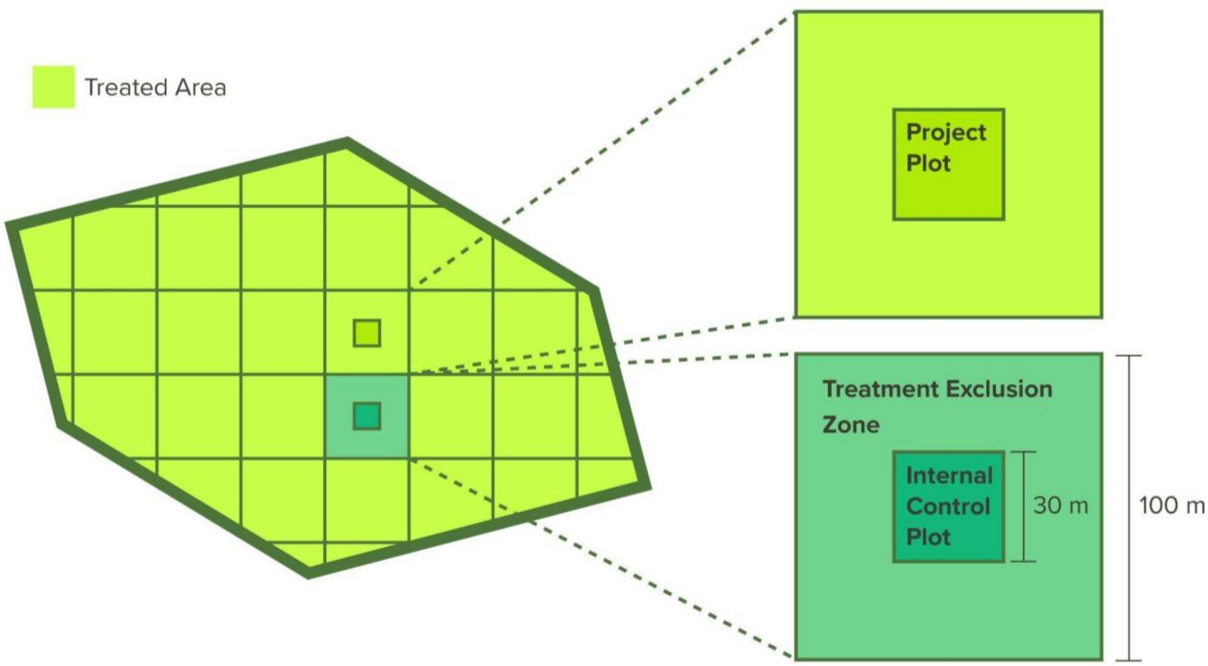

Figure 1. Hypothetical map of a project area on the left-hand side, with equal area grid cells representing potential internal control and project plot locations. On the right-hand side, these squares represent the centrally located internal control plot with treatment exclusion zone around the internal control plot, and its matched centrally located project plot. The treatment exclusion zone and the internal control plot are not subject to the project activity occurring in the project plot. The internal control plots and project plots are monitored by the project proponent.

Table A1. Optional and required variables used to match internal control plots and project plots.

Variable	Details	Optionality
Jurisdictional boundary	The jurisdictional boundary used is the national boundary. Source: The GIS layer for the jurisdictional boundary must be from a published or official national government source.	Required
Ecoregion	Defined by Olson et al 2001[49]	Required
Land tenure	At a minimum, land tenure classification must distinguish between public and private lands. More precise classifications (e.g., Indigenous reserves, concessions, private industrial lands) may be used where available. Source: Published or official government source	Required
Carbon stock	May be derived from field and/or remotely sensed observations.	Optional
Vegetation type	Dominant vegetation type	Optional
Slope	Steepness of slope (degrees)	Optional
Elevation	Meters above sea level	Optional
Land use history	For example, number of years since timber harvest, volume of timber harvested	Optional

A1.2.3 Simple Power Analysis Example

Sample size determination is required for A1.2.2, step (D) above. At minimum, the following equation should be used for sample size determination:

[49] Olson et. al 2001. Terrestrial Ecoregions of the World: A New Map of Life on Earth: A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity, *BioScience*, Volume 51, Issue 11, November 2001, Pages 933–938, https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2

$$n = (\frac{\tau CV}{E})^2$$

(Equation A1)

Where:

CV	Coefficient of variation (percent)
τ	Student t value (e.g., set to 1.96 or 95% with infinite degrees of freedom)
E	Allowable error as a percent (e.g., set to 10%[50])

The coefficient of variation may be determined using historical records, literature, or remotely sensed data. More complex power analyses may be used.

A1.2.4 Verify Internal Control Plot Location

1) This step checks whether internal control plot locations are biased in such a way that would artificially increase the additional carbon sequestration generated by the project activity. This must be checked prior to starting monitoring activities.
2) Calculate stocking index (SI) for internal control plots and project plots using at least the following three timepoints:
   a) Between *t* = -10 and t = -8
   b) Between *t* = -8 and t = -1
   c) At *t* = 0.

   SI for *t*=0 can be calculated from imagery collected in the 12 months prior to t=0 measurement in the internal control plot.
3) For each timepoint, determine whether the mean SI across all internal control plots is significantly different from the mean SI across all project plots using a two-sided t-test with 0.05 significance level.
4) If the internal control plot mean is significantly different from the project plot mean at any timepoint, then repeat selection of internal control plot locations following steps (B–E) in Section A1.2.2.

A1.3 Integrity Benchmark

To safeguard against interference with internal control plots that could artificially increase the additional carbon sequestration generated by the project activity, internal control plot integrity must be verified through comparisons with external benchmark plots located outside the project area. These external benchmark plots serve as a benchmark to validate the integrity of internal control plots within the project area, ensuring the internal control plots reflect conditions

[50] Borders and Shivers 1996 and Burkhart 2019

observed in similar external environments. External benchmark plots must be outside the control of the project developers and their partners. Creating the integrity benchmark dataset must follow A1.3.1-A1.3.4 below.

The steps for establishing the integrity benchmark must be documented in the project description in sufficient detail so that they can be reproduced and validated. All of the following steps must be fully documented as part of the monitoring plan for internal control plots and external benchmark plots as described in Section 9 of the methodology. This process is preceded by the steps for selection of internal control plot locations in Section A1.2.

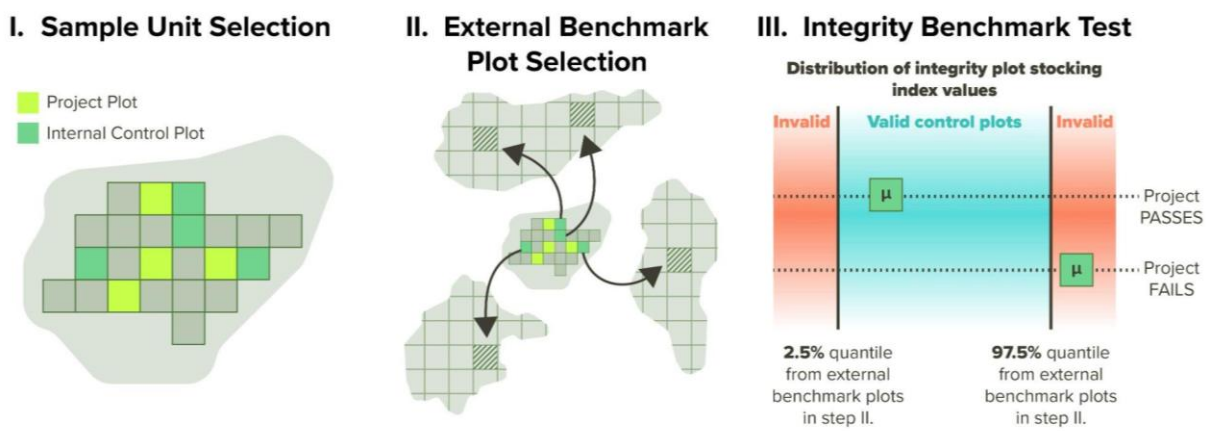

Figure 2. I) Hypothetical project boundary shown in the background while the pool of potential internal control plots and project plots is shown with a grid. Plots are randomly selected then paired in this approach using required covariate information. Plots are then randomly assigned to control (dark green) or project (neon green). Sample units are represented by a matched pair of permanently monitored internal control plot and project plots. II) External locations are selected as donor pools for potential external benchmark grid cells. III) Using the external benchmark grid cells, a 95% stocking index (SI) confidence interval is calculated. The 95% confidence interval is then used to assess the validity of the control plots. If the mean SI for control plots falls outside the 95% confidence interval for external benchmark plots, the project is considered invalid. If stratification is employed in the project, the integrity benchmark process described here should be applied independently in each stratum.

A1.3.1 Define donor pool for external benchmark plots

Define donor pool area from within which external benchmark plots may be sourced, applying the criteria in Table A3. The process to determine the donor pool area is implemented with a series of GIS overlays. The project proponent may include other spatially explicit categorical drivers of carbon regeneration, reforestation (e.g., land cover classifications), or land use history than those included in Table A3, provided their inclusion is justified on a theoretically sound or empirically demonstrated basis (e.g., peer-reviewed study). Maps used to define the donor pool and identify the external benchmark plots must have a spatial resolution no coarser than 100 m × 100 m and must be generated from source datasets no coarser than 30 m × 30 m.

Table A3. Required variables and source data to delineate donor pool area, evaluated at time *t* = 0. Time-variant geospatial layers used must be from ±5 years of *t* = 0. Where there are geospatial layers from several years, the closest available layer must be used.

Variable	Procedure and data source (GIS layer)
Jurisdictional boundary	The jurisdictional boundary used is the national boundary. Source: The GIS layer for the jurisdictional boundary must be from a published peer reviewed or official national government source.
Ecoregion[51]	The donor pool area must exclude any areas not within the same ecoregion (biome level) as the project.
Land tenure	All land tenure classifications present in the project area must be represented in the donor pool. Exclude any areas with different land tenure classification than the project area. Land tenure classification should be sourced from published or official government sources. At a minimum, land tenure classification must distinguish between public and private lands. More precise classifications (e.g., indigenous reserves, concessions, private industrial lands) may be used where available. Source: Peer reviewed publication or official government source
Distance from project area	Exclude areas beyond a 100 km radius of the project area boundary.

A1.3.2 Match internal control plots with external benchmark plots

Once the donor pool area has been delineated applying the factors in Table A3, select external benchmark plots from the donor pool to match each internal control plot, as follows.

To match external benchmark plots with internal control plots, apply a k-nearest neighbor optimal matching approach without replacement (i.e., external benchmark plots must not be matched to multiple internal control plots). Matching variables include at least three historical stocking indices. These timepoints must be from within the monitoring period, where possible, including

[51] Olson et. al 2001. Terrestrial Ecoregions of the World: A New Map of Life on Earth: A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity, *BioScience*, Volume 51, Issue 11, November 2001, Pages 933–938, https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2

the first and last years. For example, if the monitoring period was between 2020 and 2025, the timepoints could be 2020, 2023, 2025. Each internal control plot should be matched with 10–50 external benchmark plots ($9 < k < 51$). These external benchmark plots remain constant for the project duration, unless under the specific cases defined in A1.3.3, step 2.

A1.3.3 Monitoring the Integrity Benchmark

The integrity benchmark is monitored as follows:

1) At each verification event, remove any external benchmark plots deemed invalid due to their location in areas no longer matching the project area (see Table A3 above) or having undergone a land use change such that the external benchmark plot no longer matches the land use of the project.

2) In the event of partial harvest (e.g., thinning) in the project area, external benchmark plots must be replaced from the donor pool, as in Step A1.3.2. If the area is fully harvested, the integrity benchmark is no longer required.

3) Where an external benchmark plot has been deemed invalid, the plot is excluded and replaced from the donor pool, as in Step A1.3.2.

4) For all internal control plots and external benchmark plots, calculate the stocking index (SI) for at least three timepoints during the monitoring period (where possible), including the first and last years of the monitoring period. For example, for a monitoring period from 2020 to 2025, the timepoints might be 2020, 2023, and 2025. See SI parameter table for guidance on temporal constraints on imagery sourcing.

5) For each timepoint, compare the mean SI across all internal control plots within each stratum ($\mu_{bsl,s}$) to the 95% quantile calculated from the empirical distribution of the SI across all external benchmark plots matched for the stratum s:

$$[Q_{0.025}(SI_{IP,s})]$$

Where:

$Q_{0.025}$ =	Empirical quantile across observed SI in stratum s in the external benchmark plots
$SI_{IP,s}$ =	stocking indices from all external benchmark plots that are matched for stratum s

Where the mean SI_s across all control plots within stratum s is within the 95% quantile for the SI_s across all external benchmark plots matched for that stratum (see equation below), the stratum passes the integrity benchmark test for that time point. Otherwise, the stratum fails the integrity benchmark test for that time point.

$$Q_{0.025}(SI_{IP,s}) \leq \mu_{bslCP,s}$$

6) The project does not pass the integrity benchmark where any stratum fails the integrity benchmark test at any time point within the monitoring period. That is, there is insufficient evidence that the difference in removals in project plots compared to internal control plots is due to project activities, and hence, the project cannot generate VCUs for current or future verifications.

A1.3.4 Harvest intensity check

In addition to the integrity benchmark, project proponents must prove that removals have not been artificially inflated through differential harvest intensity. This is determined by calculating whether harvesting intensity is significantly higher in the internal control plots than in project plots.[52]

Harvest intensity is considered significantly higher in internal control plots than in project plots where both of the following are true:

1) $BBremoved_{bsl,s,t}$ is statistically significantly greater than $BBremoved_{wp,s,t}$ which is assessed using a one-sided t-test, as described in Equation (A2) below.
2) The mean $BBremoved_{bsl,s,t}$ is 20% higher than $BBremoved_{wp,s,t}$ as described in Equation (A9) below.[53]

The result of Equation A2 (the t-statistic) is compared to a critical value from the one-sided t-distribution at the significance level of 0.05, with degrees of freedom df = n – 1. Where the calculated t-statistic is greater than the critical value, the harvest intensity in the internal control plots is statistically significantly higher than the harvest intensity in the project plots for the monitoring period.

If the t-statistic is greater than the critical value and the percentage difference in $BBremoved_{s,t}$ is greater than 20%, the project fails the harvest intensity check and does not generate credits for current or future verifications.

$$\tau = \frac{\Delta BBremoved_{s,t}}{\frac{\hat{\sigma}_{BBremoved,s,t}}{\sqrt{n_{s,t}}}}$$

(Equation A2)

$$\Delta BBremoved_{s,t} = BBremoved_{bsl,s,t} - BBremoved_{wp,s,t}$$

(Equation A3)

$$BBremoved_{wp,s,t} = \frac{\sum_{i=1}^{n} \left(BBremoved_{saw,wt=sfw,wp,i,s,t} + BBremoved_{pulp,wt=sfw,wp,i,s,t} + BBremoved_{saw,wt=hwd,wp,i,s,t} + BBremoved_{pulp,wt=hwd,wp,i,s,t}\right)}{n_t}$$

(Equation A4)

[52] This is determined by a one-sided t-test for $BBremoved_{s,t}$ in baseline and project scenarios in each monitoring event.

[53] This test is included to avoid failing projects in which minimal differences in harvest intensity are statistically significant due to high sampling intensity.

$$BBremoved_{bsl,s,t} = \frac{\sum_{i=1}^{n_{s,t}} \left(BBremoved_{saw,wt=sfw,bsl,i,s,t} + BBremoved_{pulp,wt=sfw,bsl,i,s,t} + BBremoved_{saw,wt=hwd,bsl,i,s,t} + BBremoved_{pulp,wt=hwd,bsl,i,s,t}\right)}{n_t}$$

(Equation A5)

$$\hat{\sigma}_{BBremoved,s,t} = \frac{1}{n_{s,t}-1} \times \sum_{i=1}^{n_{s,t}} \left[\left(BBremoved_{bsl,i,s,t} - BBremoved_{wpl,i,s,t}\right) - \left(\Delta BBremoved_{s,t}\right)\right]^2$$

(Equation A6)

$$BBremoved_{wp,i,s,t} = BBremoved_{saw,wt=sfw,wp,i,s,t} + BBremoved_{pulp,wt=sfw,wp,i,s,t} + BBremoved_{saw,wt=hwd,wp,i,s,t} + BBremoved_{pulp,wt=hwd,wp,i,s,t}$$

(Equation A7)

$$BBremoved_{bsl,i,s,t} = BBremoved_{saw,wt=sfw,bsl,i,s,t} + BBremoved_{pulp,wt=sfw,bsl,i,s,t} + BBremoved_{saw,wt=hwd,bsl,i,s,t} + BBremoved_{pulp,wt=hwd,bsl,i,s,t}$$

(Equation A8)

$$Percentage\ difference = \frac{BBremoved_{bsl,s,t} - BBremoved_{wp,s,t}}{\left(\frac{BBremoved_{wp,s,t} + BBremoved_{bsl,s,t}}{2}\right)} \times 100$$

(Equation A9)

Where:

$\Delta BBremoved_{s,t}$	Difference in biomass stock removed between all project and internal control plots in stratum s in the monitoring interval ending at time *t* during which harvesting occurred (t CO_2e per unit area).
$\hat{\sigma}_{BBremoved,s,t}$	Sample standard deviation of the difference in live tree biomass stocks removed between project and internal control plots in stratum s in the monitoring interval ending at time *t* (t CO_2e per unit area)

$n_{s,t}$	Number of sample units in which stock change values are available in stratum s in year *t*
$BBremoved_{wp,s,t}$	Average biomass stocks removed in project plots in stratum *s* in the monitoring interval ending at time *t* during which harvesting occurred (t CO_2e per unit area)
$BBremoved_{bsl,s,t}$	Average biomass stocks removed in internal control plots in monitoring period ending in year *t* during which harvesting occurred (t CO_2e per unit area)
$BBremoved_{wp,i,s,t}$	Average biomass stocks removed in the treated plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* during which harvesting occurred (t CO_2e per unit area)
$BBremoved_{bsl,i,s,t}$	Average biomass stocks removed in the internal control plot in sample unit *i* in stratum s in the monitoring interval ending at time *t* during which harvesting occurred (t CO_2e per unit area)
$BBremoved_{saw,wt=sfw,wp,i,s,t}$	Saw log bole biomass stocks in wood type *wt* in commercial species removed in the project plot in sample unit *i* in stratum *s* harvested in the monitoring interval ending at time *t* (t CO_2e per unit area)
$BBremoved_{pulp,wt=sfw,wp,i,s,t}$	Pulpwood bole biomass stocks in wood type *wt* in commercial species removed in the project plot in sample unit *i* in stratum *s* harvested in the monitoring interval ending at time *t* (t CO_2e per unit area)
$BBremoved_{saw,wt=sfw,bsl,i,s,t}$	Saw log bole biomass stocks in wood type *wt* in commercial species removed in the internal control plot in sample unit *i* in stratum *s* harvested in the monitoring interval ending at time *t* (t CO_2e per unit area)
$BBremoved_{pulp,wt=sfw,bsl,i,s,t}$	Pulpwood bole biomass stocks in wood type *wt* in commercial species removed in the internal control plot in sample unit *i* harvested in the monitoring interval ending at time *t* (t CO_2e per unit area)
wt	Wood type, defined as softwood (sfw) or hardwood (hwd)

A1.4 Safeguarding against pseudo-replication

Pseudo-replication occurs when experimental units are not truly independent, leading to misleading statistical conclusions. This methodology incorporates several safeguards to prevent pseudo-replication, including:

- Randomized sampling design: A randomized sampling strategy is implemented to ensure that plot selection is unbiased and accurately represents the broader landscape.

- Paired project and internal control plots: Positioning paired project and internal control plots within the same project area enhances consistency and facilitates direct comparisons of outcomes.
- Longitudinal monitoring: Ongoing monitoring over time generates a comprehensive data set that bolsters the reliability of findings and minimizes the risk of conflating results with hidden variables.
- Integrity benchmarking: By comparing project outcomes to independent benchmarks, this methodology safeguards against biases and ensures that observed benefits are not artifacts of non-independent sampling.

These measures collectively ensure the integrity of the research design and the validity of the conclusions drawn about the carbon benefits of enhanced sequestration practices.

A1.5 Data and Parameters Monitored

Data / Parameter	*SI*
Data unit	unspecified
Description	Stocking index in internal control and project plots
Equations	N/A
Source of data	SI is an unspecified remote sensing metric with demonstrated correlation with terrestrial aboveground carbon stocks (e.g., normalized difference fraction index[54] from Landsat imagery, average canopy height derived from LiDAR, or percentage canopy cover interpreted from aerial imagery). Variability due to seasonality must be minimized (e.g., by setting a target data collection period at the project start and collecting all stocking index imagery from within that period). The target period should coincide with minimal seasonal phenological variation and where passive remote sensors are employed this should coincide with months of lowest cloud cover.
Description of measurement methods and procedures to be applied	Spatial scale/mapping unit: the stocking index must have a spatial resolution no coarser than 100 m × 100 m and must be generated from source datasets no coarser than 30 m × 30 m. Internal control and project plots may be represented by individual pixels or aggregates of pixels.
Frequency of monitoring/recording	At project validation and every monitoring/verification event
QA/QC procedures to be applied	The remote sensing metric applied must be: ● significantly correlated with terrestrial carbon stocks, at least with aboveground biomass, as previously demonstrated in published or peer-reviewed studies; or ● validated with direct measurements from the project region (collected from within the project ecoregion; ecoregion defined at the biome level following Olson et al. 2001). Processing and analysis of remote sensing data must apply established best practices, such as those found in the following publications: Global Forest Observations Initiative. 2020. Integration of Remote Sensing and Ground-based Observations for Estimation of Emissions and Removals of Greenhouse Gases in Forests: Methods and

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

	Guidance from the Global Forest Observations Initiative, edition 3.0. U.N. Food and Agriculture Organization.[55] Mitchell, A. L., A. Rosenqvist, and B. Mora. 2017. "Current remote sensing approaches to monitoring forest degradation in support of countries measurement, reporting and verification (MRV) systems for REDD+." Carbon Balance and Management 12: 9. https://doi.org/10.1186/s13021-017-0078-9 In edition 3.0, GFOI endorses using biomass and biomass change maps "as a source of auxiliary data for increasing the precision of estimates of emissions, removals and/or emissions and removals factors based on ground plot reference data" as well as indicating that "[i]n the absence of ground data, global biomass maps can be used as sources of reference data for estimating biomass." (in Chapter 4.3.1.2).
Purpose of data	Testing for bias in internal control plot location and for integrity benchmark process.
Calculation method	Dependent on remote sensing metric used
Comments	SI may be derived using different remote sensing metrics for the verification of internal control plot locations and for monitoring the integrity benchmark. It is expected that the same remote sensing technology may not be available for both the historical analysis (verifying no bias in internal control plot location) and monitoring ex-post. The same remote sensing metric must be used for monitoring SI ex-post (for integrity benchmark) in both internal control plots and external benchmark plots. Where more accurate remote sensing metrics become available over time, the remote sensing metric used for monitoring SI ex-post may be changed when all the following apply: 1. The new metric offers equivalent or better accuracy (in terms of terrestrial carbon stocks). 2. The new metric can be harmonized with the previous metric, applying procedures from peer-reviewed literature[56] to ensure data continuity and remove sources of misalignment (e.g., geometric, radiometric, and/or spectral artifacts) introduced by the new metric. 3. The procedure to harmonize the new metric incorporates temporally coincident observations of both (previous and new) remote sensing metrics from the external benchmark and control plots from within an overlap interval of at least two years, or as prescribed by the procedure.

55 Available at: https://www.fs.usda.gov/research/treesearch/61714

56 For example: https://www.usgs.gov/landsat-missions

	The location of all stocking index project, control, and external benchmark plots must be included in the project description

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

This appendix outlines a stepwise procedure for determining the significance of decreases in optional carbon pools and GHG emission sources, (E_s). Following the steps indicated below, all E_s may be deemed *de minimis* and excluded from quantification if their combined impact (in tCO_2e) is less than 5% of the total amount of carbon removals and reductions expected from the project, see Step 1, Equation (A2.1). Where the combined significance of optional pools and emissions sources is greater than 5% proceed to Step 2 Equation (A2.2) to determine which individuals carbon pools and GHG emissions sources must be included.

Project proponents may conduct a preliminary screening assessment to determine whether specific carbon pools or GHG emission sources are likely to be insignificant. This screening assessment may be based on:

(a) published literature values representative of the forest type and management conditions in the project area;

(b) a representative subset of field plots sufficient to approximate the magnitude of the pool or emission source; or

(c) other scientifically justified sources of data consistent with the ecological conditions of the project area.

Where the screening assessment demonstrates that a pool or emission source is clearly below the significance threshold defined in this Appendix, proponents may exclude that pool without compiling and/or collecting the required data. All assumptions, data sources, and calculations used in the screening assessment shall be transparently documented and subject to validation.

Where the preliminary screening assessment does not clearly demonstrate insignificance, the proponent shall apply the full significance testing procedure using the complete dataset as specified in this Appendix.

Step 1: Determine Combined Significance of E_s

$$CSR = \frac{\sum E_s}{CR} \text{ x } 100 \qquad \text{(A2.1)}$$

CSR	=	Combined Significance Ratio (%)
CR	=	Net carbon removals and reductions during the project crediting period
E_s	=	GHG project emissions and decreases in optional carbon pools

s	=	1, 2, 3, …, S sources of project GHG emissions (including leakage) and decreases in carbon pools

9 If CSR < 0.05 (i.e., less than 5%), all optional sources are deemed *de minimis*,

10 If CSR ≥ 0.05, proceed to Step 2 to determine which decreases in carbon pools and GHG emissions must be included.

Step 2: Determine Significance of Individual E_s

For each E_s, calculate its relative contributions (RC_{Es}) to the total carbon pool decrease and GHG emissions sources (E_s)

$$RC_{Es} = \frac{E_s}{\sum E_s} \tag{A2.2}$$

Where:

RC_{Es}	=	Relative contribution of each source s to the sum of project and leakage GHG emissions and decreases in optional carbon pools
E_s	=	GHG project emissions, and decreases in optional carbon pools
s	=	1, 2, 3, …, S sources of project GHG emissions (excluding leakage) and decreases in carbon pools

1) Order E_s according to their ranks from largest sources to smallest.

2) Sum RC_{Es} starting from the largest. Stop when the cumulative sum equals or exceeds 0.95.

3) Include all the sources that add up to, or exceed, 0.95.

4) Any remaining sources (those that make up the last 5%) may be excluded, but only if their combined impact is also less than 5% of total CR. If not, keep adding GHG emissions sources until that condition is met.

DOCUMENT HISTORY

Version	Date	Comment
Draft version	6 May 2026	Draft version for public stakeholder consultation