Verified Carbon Standard

Draft VCS Methodology

VM0045

IMPROVED FOREST MANAGEMENT USING DYNAMIC MATCHED BASELINES FROM NATIONAL FOREST INVENTORIES

Draft Version 1.3

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Sectoral Scope 14: Agriculture, forestry and other land use (AFOLU)

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1 SUMMARY DESCRIPTION

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

This methodology is applicable to a wide range of improved forest management (IFM) practices and employs standardized approaches for demonstration of additionality and derivation of project baselines to simplify application of the methodology.

The focus of the accounting is on the estimation of greenhouse gas (GHG) emissions and/or carbon stock change in permanent plots, not on estimation of stocks *per se*, therefore improving the precision of reported GHG emission reductions and/or carbon dioxide removals.

The methodology employs a broad monitoring and accounting framework that captures the GHG impacts of IFM practices aimed at avoiding emissions (from harvest or natural disturbance) or enhancing sequestration. Projects may apply a combination of practices implemented together in the same area.

Examples of potential activities include enrichment planting, release of natural regeneration via management of competing vegetation, stand irrigation and/or fertilization, reducing timber harvest levels, deferring harvest/extending rotations or cutting cycles, designating reserves, and altering fire severity via fuel load treatments.

For all activities, the methodology uses a matching approach to construct a quasi-experimental design with matched pairs of treatments (project) and controls (baseline), with baseline plots sourced from existing continuously measured national or sub-national forest inventory data. Carbon stock change is directly monitored in permanent sample units representing the project and baseline scenarios. The baseline is represented by a collection of sample plots outside of the project area that match the initial conditions of each paired project plot. Ex-post monitoring of the baseline in this way provides a more robust estimate of impacts compared to model- or default-driven approaches, which reflect the effects of exogenous factors like climate and timber markets on achieved GHG emission reductions.

Most IFM methodologies are dependent on long-term projections using forest growth and yield models. An important distinguishing feature of this methodology is that no forest growth and yield modeling is required to quantify GHG emission reductions and/or carbon dioxide removals. This methodology uses a dynamic performance benchmark approach, where the baseline scenario is represented by constituent baseline plots that are periodically remeasured, paired with sample units representing the project scenario.

2 SOURCES

No sources are referenced within this methodology.

3 DEFINITIONS

Composite baseline
A group of constituent baseline plots representing the baseline scenario, located outside of the project area. A composite baseline is paired to each sample unit used to monitor the project scenario and is updated over time to establish a dynamic performance benchmark for additionality and crediting baselines. Each composite baseline is derived as the optimally weighted k-nearest neighbor combination of plots that matches the initial conditions of its paired project sample unit.

Constituent baseline plot
An individual sample plot representing the baseline scenario, located outside of the project area, that constitutes a component of one or more composite baselines.

Donor pool
A population of potential sample plots located outside of the project area, from which constituent baseline plots are sourced. The donor pool is a representatively sampled, continuously measured national or sub-national forest inventory.

Project sample unit (PSU)
A permanent forest inventory plot (either fixed area or variable radius plot) used as the primary sample unit selected for measuring and monitoring carbon stock change and emissions in the project scenario. “Plot” and “sample unit” are used interchangeably within this methodology. A sample unit may constitute a collection of plots (e.g., a cluster), provided that the cluster is sampled from within a single stand. Sample units are paired with a composite baseline.

Stand[1]
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 the 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] Definition adapted from Helms, J. A. ed. 1998. *Dictionary of Forestry*. Society of American Foresters.

4 APPLICABILITY CONDITIONS

This methodology applies to all improved forest management activities, including activities representing discrete interventions and activities representing changes in management regime realized over long time horizons.

The methodology is applicable under the following conditions:

1) The project area qualifies as forests remaining as forests, and the project activity involves an intervention expected to achieve improved net carbon emission outcomes relative to business-as-usual practices.[2]

2) The project is located in a national or sub-national jurisdiction where available forest inventory datasets meet the requirements of:

    a) Appendix 1 for projects located in the United States.

    b) Appendix 2 for projects located outside the United States.

This methodology is not applicable under the following conditions:

3) The project activity involves reducing the frequency and/or intensity of timber harvest, and the project area is subject to pre-existing legal requirements that materially restrict timber harvest beyond business-as-usual practices.

4) The project activity involves a change in hydrology and/or soil disturbance exceeding 10% of the project area.

5) The project activity is classified as Wetland Restoration and Conservation (WRC).

6) The project activity involves any deliberate reduction in lying dead wood stocks that is expected to exceed 5% of net GHG emission reductions.[3]

[2] Including but not limited to extended rotations/cutting cycles, designating reserves, fuel load treatments to mitigate fire risk, enrichment planting, release of natural regeneration via management of competing vegetation, stand irrigation, and/or fertilization.

[3] As determined by applying Appendix 3 of this methodology.

5 PROJECT BOUNDARY

Spatial boundary

The spatial extent of the project boundary that encompasses all lands subject to implementation of project activities.

GHG boundary

Selected carbon pools and sources included in the project boundary are listed in Tables 1 and 2.

Appendix 3 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 the sum of all decreases in carbon stocks or increases in GHG emissions from these pools amounts to less than 5% of the total reductions and/or removals generated by the project. Optional pools may be included only where they can be accounted in both the project and baseline scenarios (i.e., these must be included in the national forest inventory data or optional enhancement datasets used for establishing the composite baseline).

Table 1. Selected carbon pools[4]

Source	Included?	Justification/Explanation
Aboveground tree biomass	Yes	Required pool. Expected to be subject to significant change due to project activity.
Aboveground non-tree woody biomass	Yes/Optional	Where this pool is subject to significant decrease due to project activity (e.g., due to site preparation), it must be included in the project scenario (and may be included in or excluded from the baseline scenario). Otherwise, this pool may be included only where it is possible to account in both the project and baseline scenarios (i.e., aboveground non-tree woody biomass must be included in the national forest inventory data used for the composite baseline).
Aboveground non-tree herbaceous biomass	No	Conservative to exclude
Belowground biomass	Yes	Expected to be subject to significant change due to the project activity

[4] Significance defined by applying Appendix 3 of this methodology.

Source	Included?	Justification/Explanation
Dead wood	Yes	Standing dead wood is required. Lying dead wood may be included only where it is possible to account for this pool in both the project and baseline scenarios (i.e., lying dead wood must be included in the national forest inventory data used for the composite baseline)[5].
Litter	Yes/Optional	Must be included where the project activity significantly reduces the carbon pool. Project proponents may choose to include this source where the change is deemed insignificant and may be included only where it is possible to account for it in both the project and baseline scenarios (i.e., this pool must be included in the national forest inventory data used for the composite baseline).
Soil organic carbon	Yes/Optional	Must be included where the project activity significantly reduces the carbon pool. Project proponents may choose to include this source where the change is deemed insignificant and may be included only where it is possible to account for it in both the project and baseline scenarios (i.e., this pool must be included in the national forest inventory data used for the composite baseline).
Wood products	Not included for reduced impact logging (RIL) with no or minimal (<25%) effect on total timber extracted Yes for all other activities	Required pool, except where the project activity involves RIL with no or minimal (<25%) effect on total timber extracted, in which case wood products must not be included.

[5] For the purposes of this methodology, lying dead wood does not include short-term harvest residues (logging slash) generated during timber operations, which are accounted for under harvest emissions and wood products where applicable.

Table 2. GHG sources included in or excluded from the project boundary[6]

Source		Gas	Included?	Justification/Explanation
Baseline and Project	Emissions from nitrogen-containing soil amendments or from decomposition of plant materials with fixed nitrogen	CO_2	N/A	N/A
		CH_4	N/A	N/A
		N_2O	Conditional on project activity	N_2O emissions from nitrogen-containing soil amendments are included in the scenario where nitrogen fertilizer is applied as part of the project activity. N_2O emissions are conservatively set to zero in the baseline.
		Other	N/A	N/A
	Burning of tree biomass (emissions from burning of non-tree biomass not included because they are de minimis)	CO_2	N/A	CO_2 from burning is effectively always included because it will be accounted for by monitoring gains and losses in required carbon pools
		CH_4	Conditional on project activity	CH_4 and N_2O emissions from fire are included in the baseline and project scenarios where incidence and/or severity of fires is impacted by the project activity (e.g., in the project scenario where the project activity involves burning woody biomass, or in the project and baseline scenarios where the project activity is aimed at altering the probability and/or magnitude of emissions from forest fires).
		N_2O	Conditional on project activity	
		Other	N/A	N/A
	Burning of fossil fuels	CO_2	No	De minimis
		CH_4	No	De minimis

[6] Significance defined by applying Appendix 3 of this methodology.

Source	Gas	Included?	Justification/Explanation
	N_2O	No	De minimis
	Other	No	De minimis

Where a carbon pool identified in the project boundary (see Table 1) as "Yes/Optional" (i.e., aboveground non-woody biomass, litter, soil organic carbon) is included in the project, the pool must be accounted for in both the baseline and project scenarios using the same calculation structure applied to mandatory pools. Specifically, baseline estimates must follow the form and logic of the equations in Section 8.1, and project estimates must follow the form and logic of the equations in Section 8.2, with pool-specific parameters substituted accordingly.

For clarity and consistency, the corresponding equations for optional pools are provided in Appendix 3. No alternative accounting structure must be applied. Inclusion of optional pools is permitted only where consistent and comparable data are available for both the project plots and the composite NFI donor pool used to construct the dynamic baseline.[7]

6 BASELINE SCENARIO

The crediting baseline uses a dynamic performance benchmark approach, where the baseline scenario is represented by designated composite baselines (made up of forest measurement plots located outside of the project area) that are continually monitored. These are paired with sample units representing the project scenario.

A group of constituent baseline plots sourced from a donor pool of national or sub-national forest inventory plots is collectively matched to project sample units and designated as a "composite baseline." Matching is achieved using a k-nearest neighbor optimal matching approach, deriving weights for constituent baseline plots to produce a weighted combination (composite baseline) that conforms to the initial conditions of the paired project sample unit. Matching conditions are defined by referencing one or more covariates representing biophysical and anthropogenic factors driving carbon stock change.

Initial conditions of composite baselines and project sample units must be matched at $t = 0$ (prior to initiation of the project activity). The selection and weighting of constituent baseline plots must be subsequently held constant throughout the project crediting period (with rare exceptions, see Section 8.1).

[7] These equations follow the same stock-change structure applied to mandatory pools and do not introduce alternative accounting approaches. Inclusion of additional pools extends the existing framework using pool-specific parameters while preserving internal consistency, comparability between baseline and project scenarios, and consistent treatment of uncertainty.

A two-stage sample is recommended for the project scenario, with primary units (e.g., stands) selected via probability proportional to size (acreage) and secondary units (e.g., plots) selected via simple random sampling (SRS) or systematic sampling with a fixed sample size within each selected primary unit (which is self-weighting and simplifies calculations). In this case, a composite baseline is matched to each primary unit on the basis of initial covariate values averaged across the secondary units.

Constituent baseline plots may be sourced from existing periodically measured national or sub-national forest inventories and must meet the following general requirements[8]:

1) Sample plots must be located outside of the project area.
2) Sample plot populations from which constituent baseline plots are sourced must be from unbiased, representative sampling at a regional scale.
3) Sample plots must be subject to periodic re-measurement throughout the project crediting period. Constituent baseline plots need not be on the same re-measurement schedule but must be re-measured every 10 years or more frequently.
4) Initial conditions must be quantified from measurements collected at time $t - 10$ or more recently.
5) Constituent baseline plots must have at least two measurement cycles to allow for carbon stock change calculations.
6) Sample plots must be located in the same ecoregion (e.g., referencing ecological sections from Cleland et al. (2007)[9] in the US or global ecoregions[10] elsewhere).
7) Sample plots must be remeasured over time using consistent plot design and measurement protocols, with sufficient spatial accuracy to ensure that the same plot area is remeasured across cycles. Systems that enable tracking of individual stems (e.g., tree identification numbers) may be used but are not required.
8) Measurement parameters (e.g., minimum diameter at breast height) must be paired with the project sample units.

[8] Detailed explanation are specified in Appendices 1 (US-based projects) and 2 (non-US-based projects).

[9] Cleland, D. T., J. A. Freeouf, J. E. Keys, G. J. Nowacki, C. A. Carpenter, and W. H. McNab. 2007. *Ecological Subregions: Sections and Subsections for the Conterminous United States.* Gen. Tech. Report WO-76D. USDA Forest Service. https://doi.org/10.2737/WO-GTR-76D

[10] Dinerstein, E., et al. 2017. An Ecoregion-Based Approach to Protecting Half the Terrestrial Realm, BioScience, Volume 67, Issue 6, June 2017, Pages 534–545, https://doi.org/10.1093/biosci/bix014

7 ADDITIONALITY

Additionality must be demonstrated using a performance method, following the steps below.

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 version of the *VCS Standard*.

Step 2: Performance Benchmark

Composite baselines derived per the procedures set out in Section 6 represent the without-project activity, or baseline scenario. Updating the composite baselines periodically throughout the project crediting period produces a dynamic and spatially variable performance benchmark in terms of periodic carbon stock change. At each monitoring event, where reductions and removals yield a positive value, the project is deemed additional.

$$ER_t = \left((A_t \times \overline{ER_t}) + LK_{ER,t}\right) \times (1 - UNC_t) \tag{1}$$

Where:

ER_t	=	Net GHG emission reductions in year *t* (t CO_2e)
A_t	=	Project area in year *t* (unit area)
$\overline{ER_t}$	=	Mean GHG emission reductions in year *t* (t CO_2e/unit area/year)
$LK_{ER,t}$	=	Leakage allocated to emission reductions in year *t* (t CO_2e)
UNC_t	=	Uncertainty in year *t* (percent)

$$CR_t = \left((A_t \times \overline{CR_t}) + LK_{CR,t}\right) \times (1 - UNC_t) \tag{2}$$

Where:

CR_t	=	Net carbon dioxide removals in year *t* (t CO_2e)
A_t	=	Project area in year *t* (unit area)
$\overline{CR_t}$	=	Mean carbon dioxide removals in year *t* (t CO_2e/unit area/year)
$LK_{CR,t}$	=	Leakage allocated to carbon dioxide removals in year *t* (t CO_2e)
UNC_t	=	Uncertainty in year *t* (percent)

8 QUANTIFICATION OF REDUCTIONS AND REMOVALS

8.1 Baseline Emissions

Baseline quantification is focused on measured carbon stock change in the composite baselines, representing the absence of project activities. Each project sample unit *i* has a corresponding paired composite baseline *i*, composed of one or more constituent baseline plots *j*.

Harvest or disturbance emissions include carbon emitted from live tree above- and belowground biomass, dead wood, and harvested wood products (i.e., carbon not retained in harvested wood products for 100 years or more after harvest).

For each constituent baseline plot, carbon stock change is calculated at re-measurement time *mt*, and annualized as:

$$\Delta LAG_{bsl,i,j,mt} = (LAG_{bsl,i,j,t} - LAG_{bsl,i,j,t-X_{bsl,i,j,t}}) \times (1/X_{bsl,i,j,t}) \quad (3)$$

$$\Delta LBG_{bsl,i,j,mt} = (LBG_{bsl,i,j,t} - LBG_{bsl,i,j,t-X_{bsl,i,j,t}}) \times (1/X_{bsl,i,j,t}) \quad (4)$$

$$\Delta DW_{bsl,i,j,mt} = (DW_{bsl,i,j,t} - DW_{bsl,i,j,t-X_{bsl,i,j,t}}) \times (1/X_{bsl,i,j,t}) \quad (5)$$

Where:

$\Delta LAG_{bsl,i,j,mt}$	=	Annual change in live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t CO_2e/unit area/year)
$LAG_{bsl,i,j,t}$	=	Live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$LAG_{bsl,i,j,t-X\_(bsl,i,j,t)}$	=	Live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time $t - X_{bsl,i,j,t}$ (t CO_2e/unit area)
$\Delta LBG_{bsl,i,j,mt}$	=	Annual change in live belowground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t CO_2e/unit area/year)
$LBG_{bsl,i,j,t}$	=	Live belowground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$LBG_{bsl,i,j,t-X\_(bsl,i,j,t)}$	=	Live belowground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time $t - X_{bsl,i,j,t}$ (t CO_2e/unit area)

$\Delta DW_{bsl,i,j,mt}$	=	Annual change in dead wood stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t CO_2e/unit area/year)
$DW_{bsl,i,j,t}$	=	Dead wood stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$DW_{bsl,i,j,t-X\_(bsl,i,j,t)}$	=	Dead wood stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time *t* – $X_{bsl,i,j,t}$ (t CO_2e/unit area)
$X_{bsl,i,j,t}$	=	Length of measurement interval ending at time *t* for constituent baseline plot *ij* (years)

Note that for the initial measurement interval, the initial measurement (*t*) must precede the project start date. The corresponding re-measurement (*mt*) may occur after the project start date, enabling estimation of baseline change over the project period..

For each reporting year *t*, annualized carbon stock change from each measurement interval is assigned to that year based on the timing of the corresponding re-measurement (*mt*). Specifically, values are included where the difference between the reporting year and the re-measurement time ($t - m_t$) is less than the length of the associated measurement interval ($X_{bsl,i,j,t}$). This ensures that each reporting year incorporates carbon stock change estimates derived from temporally relevant measurement intervals. The resulting annualized values are summed across all constituent baseline plots. Then, the composite baseline *i* is calculated as the weighted sum of carbon stock change across constituent baseline plots. Note that constituent plots within a given composite baseline do not need to follow the same re-measurement schedule and may be measured at different, non-fixed intervals throughout the crediting period.

$$\Delta LAG_{bsl,i,t} = \sum_{j=1}^{n} W_{bsl,i,j} \sum_{mt=-10}^{t} \Delta LAG_{bsl,i,j,mt} \; [t - mt < X_{bsl,i,j,t}] \quad (6)$$

$$\Delta LBG_{bsl,i,t} = \sum_{j=1}^{n} W_{bsl,i,j} \sum_{mt=-10}^{t} \Delta LBG_{bsl,i,j,mt} \; [t - mt < X_{bsl,i,j,t}] \quad (7)$$

$$\Delta DW_{bsl,i,t} = \sum_{j=1}^{n} W_{bsl,i,j} \sum_{mt=-10}^{t} \Delta DW_{bsl,i,j,mt} \; [t - mt < X_{bsl,i,j,t}] \quad (8)$$

Where:

$\Delta LAG_{bsl,i,t}$	=	Annual change in live aboveground biomass stocks in the baseline scenario at composite baseline *i* in year *t* (t CO_2e/unit area/year)
$\Delta LAG_{bsl,i,j,mt}$	=	Annual change in live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t CO_2e/unit area/year)
$\Delta LBG_{bsl,i,t}$	=	Annual change in live belowground biomass stocks in the baseline scenario at composite baseline *i* in year *t* (t CO_2e/unit area/year)

$\Delta LBG_{bsl,i,j,mt}$	=	Annual change in live belowground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t CO_2e/unit area/year)
$\Delta DW_{bsl,i,t}$	=	Annual change in dead wood stocks in the baseline scenario at composite baseline *i* in year *t* (t CO_2e/unit area/year)
$\Delta DW_{bsl,i,j,mt}$	=	Annual change in dead wood stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t CO_2e/unit area/year)
$W_{bsl,i,j}$	=	Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1 (dimensionless)

Table 3 gives an example of applying Equations (3) and (6) to derive live aboveground biomass stock change for a composite baseline.

Table 3. Illustrative derivation of live aboveground biomass stock change for a composite baseline applying Equations (3) and (6)

a) **Periodic measurement of live aboveground biomass in constituent baseline plots ($LAG_{bsl,i,j,t}$ – Units in tCO_2e/unit area)**

Plot *bsl,i,j*	Year *t*												
	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5
1	430.3							325.7				338.7	
2			260.1					284.6					
3		233.7					247.3						238.2
4	335.6					361.7							387.4
5			459.4					474.8					
6				214.2				230.2					
7			195.8					216.2					
8	195.0					145.4					165.3		
9		80.0					91.2					86.7	
10		190.0				152.0					170.0		

Table 3 (cont…). Illustrative derivation of live aboveground biomass stock change for a composite baseline applying Equations (3) and (6)

b) **Calculation of annual change in live aboveground biomass stocks in constituent baseline plots at re-measurement time *mt* ($\Delta LAG_{bsl,i,j,mt}$)**

Plot bsl,i,j	Time $mt - X_{bsl,i,j,t}$	Time mt	$LAG_{bsl,i,j,t-X\_(bsl,i,j,t)}$ (t CO_2e/unit area)	$LAG_{bsl,i,j,t}$ (t CO_2e/unit area)	$X_{bsl,i,j,t}$ (years)	$LAG_{bsl,i,j,t} - LAG_{bsl,i,j,t-X\_(bsl,i,j,t)}$ (t CO_2e/unit area)	$\Delta LAG_{bsl,i,j,mt}$ (t CO_2e/unit area/year)
1	−7	0	430.3	325.7	7	−104.6	−14.9
1	0	4	325.7	338.7	4	13.0	3.2
2	−5	0	260.1	284.6	5	24.5	4.9
3	−6	−1	233.7	247.3	5	13.6	2.7
3	−1	5	247.3	238.2	6	−9.1	−1.5
4	−7	−2	335.6	361.7	5	26.1	5.2
4	−2	5	361.7	387.4	7	25.7	3.7
5	−5	0	459.4	474.8	5	15.4	3.1
6	−4	0	214.2	230.2	4	16.0	4.0
7	−5	0	195.8	216.2	5	20.4	4.1
8	−7	−2	195.0	145.4	5	−49.6	−9.9
8	−2	3	145.4	165.3	5	19.9	4.0
9	−6	−1	80	91.2	5	11.2	2.2
9	−1	4	91.2	86.7	5	−4.5	−0.9
10	−6	−2	190	152	4	−38.0	−9.5
10	−2	3	152	170	5	18.0	3.6

Table 3 (cont…). Illustrative derivation of live aboveground biomass stock change for a composite baseline applying Equations (3) and (6)

c) **Calculation of change in live aboveground biomass stocks in composite control *i* in year *t* ($\Delta LAG_{bsl,i,t}$)**

Plot bsl,i,j	$W_{bsl,i,j}$	Year t				
		1	2	3	4	5
1	0.08	−14.9	−14.9	−14.9	−11.7	−11.7
2	0.05	4.9	4.9	4.9	4.9	0.0
3	0.05	2.7	2.7	2.7	0.0	−1.5
4	0.05	5.2	5.2	0.0	0.0	3.7
5	0.17	3.1	3.1	3.1	3.1	0.0
6	0.11	4.0	4.0	4.0	0.0	0.0
7	0.10	4.1	4.1	4.1	4.1	0.0
8	0.17	−9.9	−9.9	4.0	4.0	4.0
9	0.16	2.2	2.2	2.2	−0.9	−0.9
10	0.05	−9.5	0.0	3.6	3.6	3.6
	$\Delta LAG_{bsl,i,t}$	−1.0	−0.5	1.7	0.9	−0.2

Note that in this example, initial measurement occurred at t = -7 or seven years prior to t = 0. In plot 1, for example, -14.9 t CO_2e/unit area/year is the annual change in live aboveground biomass for the first measurement period. Years 4 and 5 reflect the annual stock change after plot 1 was remeasured at year 4 (-14.9 + 3.2 = -11.7). See Table 3a and 3b above.

Weights for constituent baseline plots ($W_{bsl,i,j}$) are determined at t = 0 and fixed throughout the project crediting period, except where a constituent baseline plot has become invalid (e.g., where a unit is no longer in a forest condition or has not been re-measured in over 10 years; see Section 6). In this case, all weights in the respective composite baseline are recalculated to sum to one, holding relative weights of the remaining valid constituent plots constant.

Harvested wood product stocks ($HWP_{bsl,i,j,t}$) are calculated using Equation (9).

$$HWP_{bsl,i,j,t} = \left(BBremoved_{saw,wt=sfw,bsl,i,j,t} \times SF_{saw,wt=sfw} + BBremoved_{pulp,wt=sfw,bsl,i,j,t} \times SF_{pulp,wt=sfw}\right) + \left(BBremoved_{saw,wt=hwd,bsl,i,j,t} \times SF_{saw,wt=hwd} + BBremoved_{pulp,wt=hwd,bsl,i,j,t} \times SF_{pulp,wt=hwd}\right) \quad (9)$$

Where:

$HWP_{bsl,i,j,t}$	=	Harvested wood products remaining stored for 100 years in the baseline scenario at constituent baseline plot *j* in composite baseline *i*, harvested in the monitoring interval ending at time *t* (t CO_2e/unit area)
$BBremoved_{saw,wt,bsl,i,j,t}$	=	Saw log bole biomass stocks in wood type *wt* in commercial species removed in the baseline scenario at constituent baseline plot *j* in composite baseline *i,* harvested in the monitoring interval ending at time *t* (t CO_2e/unit area)
$BBremoved_{pulp,wt,bsl,i,j,t}$	=	Pulpwood bole biomass stocks in wood type *wt* in commercial species removed in the baseline scenario at constituent baseline plot *j* in composite baseline *i,* harvested in the monitoring interval ending at time *t* (t CO_2e/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 conifers (sfw) or broadleaves (hwd)

Where burning occurs in the monitoring interval ending at time *t*, CH_4 and N_2O emissions from fire are included and calculated using Equation (10), assuming that all stock change is subject to burning. Otherwise, $Bburn_{bsl,i,j,t}$ is set equal to zero.

$$Bburn_{bsl,i,j,t} = \sum_{g=1}^{G} GWP_g \times \left((LAG_{bsl,i,j,t} - LAG_{bsl,i,j,t-X_{bsl,i,j,t}}) + (DW_{bsl,i,j,t} - DW_{bsl,i,j,t-X_{bsl,i,j,t}}) \right) \times \frac{12}{44} \times \frac{1}{CF} \times C_f \times EF_g \times 10^{-3} \quad (10)$$

Where:

$Bburn_{bsl,i,j,t}$	=	Emissions of CH_4 and N_2O in the baseline scenario from biomass burning at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
GWP_g	=	Global warming potential of gas *g*
$LAG_{bsl,i,j,t}$	=	Live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time *t* (t CO_2e/unit area)
$LAG_{bsl,i,j,t-X\_(bsl,i,j,t)}$	=	Live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time $t - X_{bsl,i,j,t}$ (t CO_2e/unit area)
$DW_{bsl,i,j,t}$	=	Dead wood stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time *t* (t CO_2e/unit area)
$DW_{bsl,i,j,t-X\_(bsl,i,j,t)}$	=	Dead wood stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time $t - X_{bsl,i,j,t}$ (t CO_2e/unit area)
CF	=	Carbon fraction; 0.47
C_f	=	Combustion factor (dimensionless)
EF_g	=	Emission factor for gas *g* (g/kg dry matter burned)

Carbon stock change and emissions in the baseline scenario are then estimated for each composite baseline *i* at time *t* (net sequestration), which serves as the performance benchmark (crediting baseline) for each paired project sample unit *i*, as:

$$\Delta CO2_{bsl,i,t} = \Delta LAG_{bsl,i,t} + \Delta LBG_{bsl,i,t} + \Delta DW_{bsl,i,t} + \sum_{j=1}^{n} (HWP_{bsl,i,j,t} \times W_{bsl,i,j}) \quad (11)$$

Where:

$\Delta CO2_{bsl,i,t}$	=	Carbon stock change in the baseline scenario in composite baseline *i* in year *t* (t CO_2e/unit area/year)
$\Delta LAG_{bsl,i,t}$	=	Annual change in live aboveground biomass stocks in the baseline scenario in composite baseline *i* in year *t* (t CO_2e/unit area/year)
$\Delta LBG_{bsl,i,t}$	=	Annual change in live belowground biomass stocks in the baseline scenario in composite baseline *i* in year *t* (t CO_2e/unit area/year)
$\Delta DW_{bsl,i,t}$	=	Annual change in dead wood stocks in the baseline scenario in composite baseline *i* in year *t* (t CO_2e/unit area/year)

$HWP_{bsl,i,j,t}$	=	Harvested wood products remaining stored over 100 years in the baseline scenario at constituent baseline plot *j* in composite baseline *i*, harvested in the monitoring interval ending at time *t* (t CO_2e/unit area)

$$BE_{i,t} = Nfert_{bsl,i,t} + \sum_{j=1}^{n}(Bburn_{bsl,i,j,t} \times W_{bsl,i,j}) \quad (12)$$

Where:

$BE_{i,t}$	=	Baseline emissions in composite baseline *i* in year *t* (t CO_2e/unit area/year)
$Nfert_{bsl,i,t}$	=	Direct and indirect nitrous oxide emissions due to nitrogen fertilizer use in the baseline scenario in composite baseline *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$Bburn_{bsl,i,j,t}$	=	Emissions of methane and nitrous oxide in the baseline scenario from biomass burning at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$W_{bsl,i,j}$	=	Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1 (dimensionless)

Nitrous oxide emissions due to nitrogen fertilizer use in the baseline scenario ($Nfert_{bsl,i,t}$) are conservatively set to zero.

8.2 Project Emissions

Stock change in live aboveground biomass in the project scenario in sample unit *i* over the monitoring interval ending at time *t* is annualized as:

$$\Delta LAG_{wp,i,t} = (LAG_{wp,i,t} - LAG_{wp,i,t-X_{wp,i,t}}) \times (1/X_{wp,i,t}) \quad (13)$$

$$\Delta LBG_{wp,i,t} = (LBG_{wp,i,t} - LBG_{wp,i,t-X_{wp,i,t}}) \times (1/X_{wp,i,t}) \quad (14)$$

$$\Delta DW_{wp,i,t} = (DW_{wp,i,t} - DW_{wp,i,t-X_{wp,i,t}}) \times (1/X_{wp,i,t}) \quad (15)$$

Where:

$\Delta LAG_{wp,i,t}$	=	Average annual change in live aboveground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area/year)
$LAG_{wp,i,t}$	=	Live aboveground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$LAG_{wp,i,t-X\_(wp,i,t)}$	=	Live aboveground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time $t - X_{wp,i,t}$ (t CO_2e/unit area)
$\Delta LBG_{wp,i,t}$	=	Average annual change in live belowground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area/year)
$LBG_{wp,i,t}$	=	Live belowground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)

$LBG_{wp,i,t-X\_(wp,i,t)}$	=	Live belowground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time $t - X_{wp,i,t}$ (t CO_2e/unit area)
$\Delta DW_{wp,i,t}$	=	Average annual change in dead wood stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area/year)
$DW_{wp,i,t}$	=	Dead wood stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$DW_{wp,i,t-X\_(wp,i,t)}$	=	Dead wood stocks in the project scenario in sample unit *i* in the monitoring interval ending at time $t - X_{wp,i,t}$ (t CO_2e/unit area)
$X_{wp,i,t}$	=	Length of measurement interval ending at time *t* for sample unit *i* in the project scenario (years)

As with constituent baseline plots, project sample units may be re-measured on a staggered basis (i.e., re-measurements of cohorts of sample units are scheduled in different years within a monitoring cycle), provided that subsets of sample units in the project scenario re-measured in different years are selected systematically or at random from the total sample population.

Harvested wood products remaining stored for 100 years ($HWP_{wp,i,t}$) and emissions of CH_4 and N_2O from biomass burning ($Bburn_{wp,i,t}$) in the project scenario are estimated using Equations (9) and (10) respectively, substituting the subscript *bsl* with *wp* to make clear that the relevant values are being quantified for the project scenario. Note that no weighted summing operation is used in these equations in the project scenario.

Where nitrogen fertilizer is applied due to the project activity, nitrous oxide emissions are calculated using Equation (16).

$$Nfert_{wp,i,t} = Nfert_{wp,direct,i,t} + Nfert_{wp,indirect,i,t} \quad (16)$$

Where:

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

$$Nfert_{wp,direct,i,t} = \left(F_{wp,SN,i,t} + F_{wp,ON,i,t}\right) \times EF_{Ndirect} \times 44/28 \times GWP_{N2O} \quad (17)$$

$$F_{wp,SN,i,t} = M_{wp,SF,i,t} \times NC_{wp,SF,i,t} \quad (18)$$

$$F_{wp,ON,i,t} = M_{wp,OF,i,t} \times NC_{wp,OF,i,t} \quad (19)$$

Where:

$Nfert_{wp,direct,i,t}$	=	Direct nitrous oxide emissions due to nitrogen fertilizer use in the project scenario for sample unit *i* in the monitoring interval ending at *t* (t CO_2e/unit area)
$F_{wp,SN,i,t}$	=	Project synthetic nitrogen fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t N/unit area)
$F_{wp,ON,i,t}$	=	Project organic nitrogen fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t N/unit area)
$M_{wp,SF,i,t}$	=	Mass of project nitrogen-containing synthetic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t fertilizer/unit area)
$M_{wp,OF,i,t}$	=	Mass of project nitrogen-containing organic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t fertilizer/unit area)
$NC_{wp,SF,i,t}$	=	Nitrogen content of project synthetic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t N/t fertilizer)
$NC_{wp,OF,i,t}$	=	Nitrogen content of project organic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t N/t fertilizer)
$EF_{Ndirect}$	=	Emission factor for nitrous oxide emissions from nitrogen additions from synthetic fertilizers, organic amendments, and crop residues (t N_2O-N/t N applied)
GWP_{N2O}	=	Global warming potential for nitrous oxide; 298

$$Nfert_{wp,indirect,i,t} = Nfert_{wp,volat,i,t} + Nfert_{wp,leach,i,t} \tag{20}$$

$$Nfert_{wp,volat,i,t} = \left[\left(F_{wp,SN,i,t} \times Frac_{GASF}\right) + \left(F_{wp,ON,i,t} \times Frac_{GASM}\right)\right] \times EF_{Nvolat} \times 44/28 \times GWP_{N2O} \tag{21}$$

$$Nfert_{wp,leach,i,t} = \left(F_{wp,SN,i,t} + F_{wp,ON,i,t}\right) \times Frac_{LEACH} \times EF_{Nleach} \times 44/28 \times GWP_{N2O} \tag{22}$$

Where:

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

$F_{wp,ON,i,t}$	=	Project organic nitrogen fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t N/unit area)
$Frac_{GASF}$	=	Fraction of all synthetic nitrogen added to soils that volatilizes as ammonia and NO_x (dimensionless)
$Frac_{GASM}$	=	Fraction of all organic nitrogen added to soils that volatilizes as ammonia and NO_x (dimensionless)
$Frac_{LEACH}$	=	Fraction of nitrogen (synthetic and organic) added to soils that is lost through leaching and runoff, in regions where leaching and runoff occurs (dimensionless)
EF_{Nvolat}	=	Emission factor for nitrous oxide emissions from atmospheric deposition of nitrogen 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_{N2O}	=	Global warming potential for nitrous oxide; 298

Carbon stock change and emissions in the project scenario are then estimated for each sample unit *i* in year *t* using Equations (23) and (24).

$$\Delta CO2_{wp,i,t} = \Delta LAG_{wp,i,t} + \Delta LBG_{wp,i,t} + \Delta DW_{wp,i,t} + HWP_{wp,i,t} \quad (23)$$

Where:

$\Delta CO2_{wp,i,t}$	=	Average annual carbon stock change in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area/year)
$\Delta LAG_{wp,i,t}$	=	Average annual change in live aboveground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area/year)
$\Delta LBG_{wp,i,t}$	=	Average annual change in live belowground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area/year)
$\Delta DW_{wp,i,t}$	=	Average annual change in dead wood stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area/year)
$HWP_{wp,i,t}$	=	Harvested wood products remaining stored over 100 years in the project scenario in sample unit *i,* harvested in the monitoring interval ending at time *t* (t CO_2e/unit area)

$$PE_{i,t} = Nfert_{wp,i,t} + Bburn_{wp,i,t} \quad (24)$$

Where:

$PE_{i,t}$	=	Project emissions in composite baseline *i* in year *t* (t CO_2e/unit area)

$Nfert_{wp,i,t}$	=	Direct and indirect nitrous oxide emissions due to nitrogen fertilizer use in the project scenario for sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$Bburn_{wp,i,t}$	=	Emissions of methane and nitrous oxide in the project scenario from biomass burning in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)

Note that any emissions resulting from an initial project treatment (e.g., prescribed burn or thinning) are included in parameter $\Delta CO2_{wp,i,t}$ because the first monitoring interval begins immediately prior to application of the project activity.

8.3 Leakage Emissions

Leakage is due to a combination of 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_t) is calculated as:

$$LK_t = MIN\ (0,\ A_t \times \frac{1}{n}\sum_{i=1}^{n}\left(LTremoved_{wp,i,t} - \sum_{j=1}^{n} LTremoved_{bsl,i,j,t} \times W_{bsl,i,j}\right) \times LF_t\ ) \qquad (25)$$

Where:

LK_t	=	Leakage in year *t* (t CO_2e)
$LTremoved_{wp,i,t}$	=	Live tree biomass stocks removed in the project scenario in sample unit *i* subject to harvest in the monitoring interval ending at time *t* (t CO_2e/unit area)
$LTremoved_{bsl,i,j,t}$	=	Live tree biomass stocks removed in the baseline scenario (without avoided emissions activity), at constituent baseline plot *j* in composite baseline *i* subject to harvest in the monitoring interval ending at time *t* (t CO_2e/unit area)
$W_{bsl,i,j}$	=	Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1 (dimensionless)
LF_t	=	Leakage factor (percent)
A_t	=	Project area in year *t* (unit area)

The leakage factor (LF_t) is determined per the following stepwise process:

1) Determine whether the project activity involves any permanent reduction in timber supply (i.e., involves any commitment to reduce harvest levels for 100 years or longer), demonstrated at the project start date.
2) Where the project activity involves any permanent reduction in timber supply, calculate the national average ratio of merchantable stocking (on a volume or mass basis in

commercial species) to total stocking and compare this to the equivalent ratio in the project area. The value of LF_t is determined based on this comparison as follows:

a) Where the two ratios are equal (i.e., national ratio within ±15% of the project area ratio): LF_t = 0.4 (40%)

b) Where the national ratio is less than that in the project area (i.e., national ratio <85% of the project area ratio): LF_t = 0.7 (70%)

c) Where the national ratio is greater than that in the project area (i.e., national ratio >115% of the project area ratio): LF_t = 0.2 (20%)

3) Otherwise, where the project activity involves no permanent reduction in timber supply, LF_t = 0.1 (10%).

8.4 Net Reductions and Removals

Net GHG emission reductions in each year are quantified as:

$$ER_t = \left(\left(A_t \times \overline{ER_t}\right) + LK_{ER,t}\right) \times (1 - UNC_t) \tag{26}$$

Where:

ER_t	=	Net GHG emission reductions in year t (t CO_2e)
A_t	=	Project area in year t (unit area)
$\overline{ER_t}$	=	Mean GHG emission reductions in year t (t CO_2e/unit area/year)
$LK_{ER,t}$	=	Leakage allocated to GHG emission reductions in year t (t CO_2e)
UNC_t	=	Uncertainty in year t (percent)

Net carbon dioxide removals in each year are quantified as:

$$CR_t = \left(\left(A_t \times \overline{CR_t}\right) + LK_{CR,t}\right) \times (1 - UNC_t) \tag{27}$$

Where:

CR_t	=	Net carbon dioxide removals in year t (t CO_2e)
A_t	=	Project area in year t (unit area)
$\overline{CR_t}$	=	Mean carbon dioxide removals in year t (t CO_2e/unit area/year)
$LK_{CR,t}$	=	Leakage allocated to carbon dioxide removals in year t (t CO_2e)
UNC_t	=	Uncertainty in year t (percent)

Leakage allocated to GHG emission reductions ($LK_{ER,t}$) is calculated as:

$$LK_{ER,t} = LK_t \times \frac{\overline{ER_t}}{\overline{ER_t} + \overline{CR_t}} \tag{28}$$

Where:

$LK_{ER,t}$	=	Leakage allocated to GHG emission reductions in year t (t CO_2e)
LK_t	=	Leakage in year t (t CO_2e)
$\overline{ER_t}$	=	Mean GHG emission reductions in year t (t CO_2e/unit area/year)
$\overline{CR_t}$	=	Mean carbon dioxide removals in year t (t CO_2e/unit area/year)

Leakage allocated to carbon dioxide removals ($LK_{CR,t}$) is calculated as:

$$LK_{CR,t} = LK_t \times \frac{\overline{CR_t}}{\overline{ER_t} + \overline{CR_t}} \quad (29)$$

Where:

$LK_{CR,t}$	=	Leakage allocated to carbon dioxide removals in year t (t CO_2e)
LK_t	=	Leakage in year t (t CO_2e)
$\overline{ER_t}$	=	Mean GHG emission reductions in year t (t CO_2e)
$\overline{CR_t}$	=	Mean carbon dioxide removals in year t (t CO_2e)

The mean GHG emission reductions and mean carbon dioxide removals in year t are affected by the carbon stock change in the baseline scenario in the following way:

Where the baseline carbon stock decreases from year t to year $t + 1$, emissions are occurring. In the project scenario, these emissions are avoided because of the project activities. Hence, a baseline carbon stock decrease results in GHG emission reductions in the same year.

Where the baseline carbon stock increases from year t to year $t + 1$, removals are occurring. The amount of removals occurring in the project scenario must be adjusted to reflect removals achieved in the absence of project activities. Hence, a baseline carbon stock increase results in decreased removals in the same year.

The mean GHG emission reductions and mean carbon dioxide removals in year t are affected by the cumulative carbon stock change in the project scenario in the following way:

a) Where the cumulative carbon stock change in the project scenario is positive (i.e., the project carbon stock is greater in year t than at the project start date), removals are generated.

b) Where the cumulative carbon stock change in the project scenario is negative (i.e., the project carbon stock is smaller in year t than at the project start date), reductions are generated.

Emission reductions are calculated for each sample unit i in year t, and the mean GHG emission reduction is quantified as:

$$\overline{ER_t} = I(\Delta CO2_{wp}) \times \frac{1}{n} \times \sum_{i=1}^{n} (-PE_{i,t} - MIN(0, \Delta CO2_{bsl,i,t}) + MIN(0, \Delta CO2_{wp,i,t})) + (1 - I(\Delta CO2_{wp})) \times \frac{1}{n} \times \sum_{i=1}^{n} (PE_{i,t} - BE_{i,t} - MIN(0, \Delta CO2_{bsl,i,t}) + MIN(0, \Delta CO2_{wp,i,t}) + MAX(0, \Delta CO2_{wp,i,t}) - MAX(0, \Delta CO2_{bsl,i,t})) \quad (30)$$

Where:

$I(\Delta CO2_{wp}) = 1$, if $\sum_{i=1}^{n} \sum_{m=1}^{t} \Delta CO2_{wp,i,m} > 0$ and;

$I(\Delta CO2_{wp}) = 0$, if $\sum_{i=1}^{n} \sum_{m=1}^{t} \Delta CO2_{wp,i,m} \leq 0$

$\overline{ER_t}$	=	Mean GHG emission reductions in year *t* (t CO_2e/unit area/year)
$PE_{i,t}$	=	Project emissions in composite baseline *i* in year *t* (t CO_2e/unit area/year)
$BE_{i,t}$	=	Baseline emissions in composite baseline *i* in year *t* (t CO_2e/unit area/year)
$\Delta CO2_{bsl,i,t}$	=	Carbon stock change in the baseline scenario in composite baseline *i* in year *t* (t CO_2e/unit area/year)
$\Delta CO2_{wp,i,t}$	=	Average annual carbon stock change in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area/year)
$\Delta CO2_{wp,i,m}$	=	Carbon stock change in the project scenario in sample unit *i* in year *m* (t CO_2e/unit area/year)
n	=	Number of sample units in which stock change values are available for both the project and baseline scenarios

Carbon dioxide removals are calculated for each sample unit *i* in year *t*, and the mean carbon dioxide removal is quantified as:

$$\overline{CR_t} = I(\Delta CO2_{wp}) \times \frac{1}{n} \times \sum_{i=1}^{n} (MAX(0, \Delta CO2_{wp,i,t}) - MAX(0, \Delta CO2_{bsl,i,t})) \quad (31)$$

Where:

$I(\Delta CO2_{wp}) = 1$ if $\sum_{i=1}^{n} \sum_{m=1}^{t} \Delta CO2_{wp,i,m} > 0$ and;

$I(\Delta CO2_{wp}) = 0$ if $\sum_{i=1}^{n} \sum_{m=1}^{t} \Delta CO2_{wp,i,m} \leq 0$

$\overline{CR_t}$	=	Mean carbon dioxide removals in year *t* (t CO_2e/unit area/year)
$\Delta CO2_{wp,i,t}$	=	Average annual carbon stock change in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO2e/unit area/year)
$\Delta CO2_{wp,i,m}$	=	Carbon stock change in the project scenario in sample unit *i* in year *m* (t CO_2e/unit area/year)

$\Delta CO2_{bsl,i,t}$	=	Carbon stock change in the baseline scenario in composite baseline *i* in year *t* (t CO_2e/unit area/year)
n	=	Number of sample units in which stock change values are available for both the project and baseline scenarios

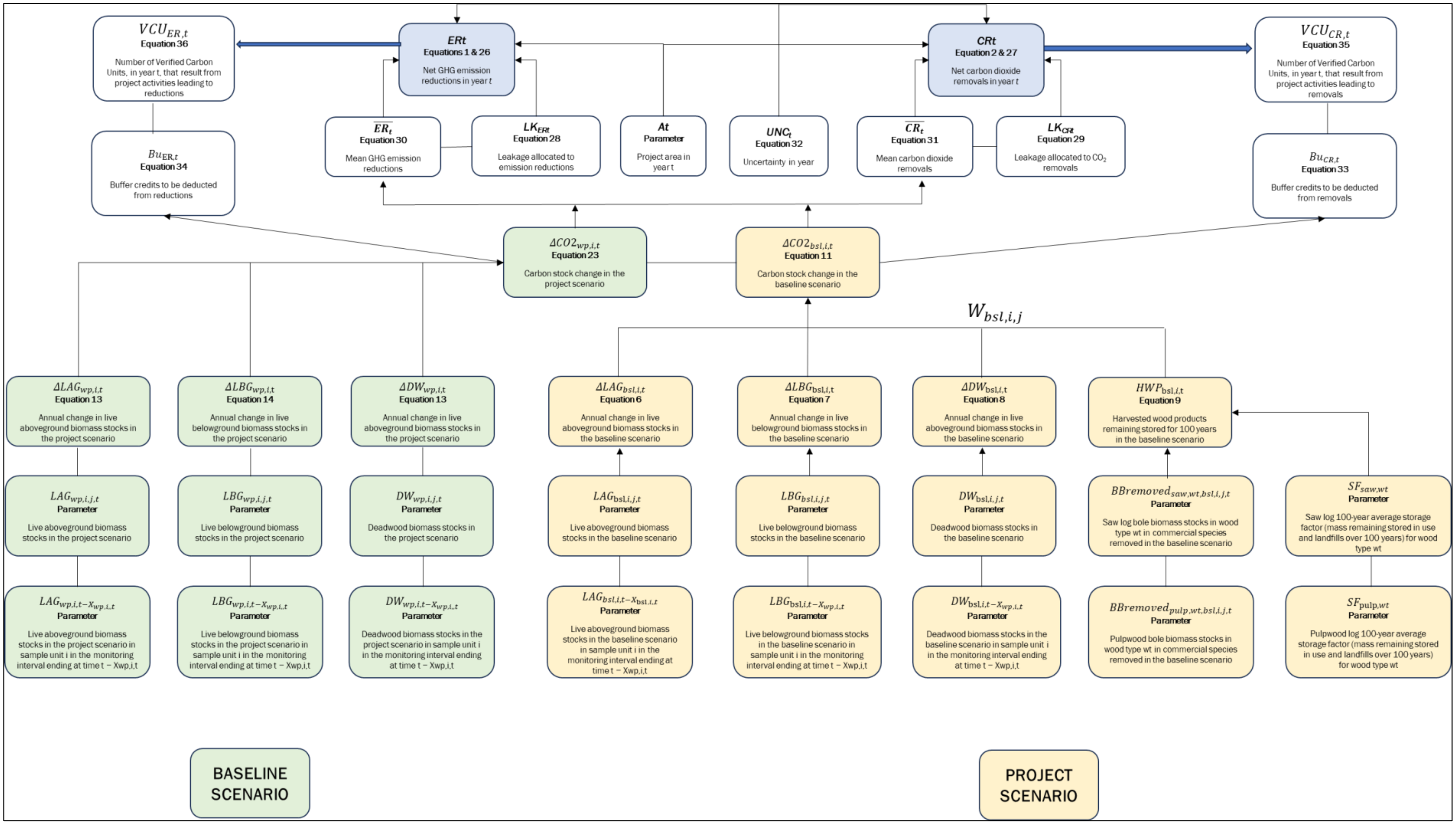
Mean carbon stock change and GHG emission reductions are calculated using unbiased estimators, such as from Cochran, W. G. 1977. *Sampling Techniques.* 3rd ed. John Wiley & Sons or Som, R. K. 1995. *Practical Sampling Techniques.* 2nd ed. Taylor & Francis. Equations (30), (31), and (32), used to calculate ER_t, CR_t, and UNC_t, assume either:

1) a simple random sample (SRS) design; or

a two-stage sample with primary units (e.g., stands) selected via probability proportional to size (acreage) and secondary units (e.g., plots) selected via SRS or systematic sampling with a fixed sample size within each selected primary unit. In the latter case, a composite baseline would be matched to each primary unit on the basis of initial conditions averaged across the secondary units (many-to-many matching).

Other statistically robust sample designs (e.g., stratified samples) may be employed, and the estimators of the mean and standard error reconfigured to permit unbiased estimation. Note that in Equations (30) and (31) only sample units *i* for which calculated stock change values at time *t* are available for both the project and baseline scenarios are included (i.e., two measurement events must have taken place in a sample unit and all of its matched constituent control plots before a paired sample *i* is included in the calculation of net GHG emission reductions). Calculations are summarized in Figure 1 below.

Figure 1. Summary of calculations in VM0045



8.5 Uncertainty

Uncertainty associated with sampling error must be quantified and accounted for following the procedures specified in Appendix 1 (for projects located in the United States) or Appendix 2 (for projects located outside the United States).

For projects located in the United States (Appendix 1), project proponents must recognize that uncertainty in area estimates is unlikely to be zero due to the spatial distribution and sampling density of the Forest Inventory and Analysis (FIA) plots. To address this, project proponents must implement a matching and weighting procedure that ensures composite baseline plots are appropriately representative of project conditions. The weighting term ($W_{bsl,i,j}$) accounts for the relative influence of each constituent plot, and project proponents must quantify and propagate associated uncertainty in baseline emissions or removals using Equation (32).

For projects located outside the United States (Appendix 2) specifies equivalent procedures based on the national or sub-national forest inventory in use. These procedures must account for differences in sampling design, plot density, and representativeness through matching and weighting techniques, ensuring that composite baseline plots or strata are statistically representative of project conditions.

Uncertainty in project area (A_t) is assumed to be zero when complete and verified GIS boundaries are used. Regardless of project location, project proponents must apply QA/QC measures and propagate uncertainty in baseline emissions or removals as defined in the corresponding appendix to ensure conservative estimates. By applying weighted combinations of well-matched plots and excluding poorly matched outliers, this approach minimizes potential bias and supports the conservativeness of baseline estimates.

GHG emission reductions and carbon dioxide removals are estimated from paired composite baselines and project sample units, and uncertainty (UNC_t) is calculated as follows:

$$UNC_t = MIN(100\%, MAX\ (0, T \times \left(\left|\frac{1}{n} \times s_{wp,t}^2 + \frac{1}{n^2} \times \sum_{j=1}^{c}(\sum_{i=1}^{n} W_{bsl,i,j}{}^2 \times s_{bsl,t}^2\right|)\right)^{\frac{1}{2}} \times \left(\frac{1}{\overline{ER_t} + \overline{CR_t}}\right) - 15\%)) \quad (32)$$

Where:

UNC_t	=	Uncertainty in year t, expressed as the half width of the 95% confidence interval as a percentage of the mean (percent)
$s_{wp,t}^2$	=	Variance of stock change in the project scenario in the monitoring interval ending in year t (dimensionless)
$s_{bsl,t}^2$	=	Variance of stock change in the baseline scenario in the monitoring interval ending in year t (dimensionless)
$W_{bsl,i,j}$	=	Weight of constituent baseline plot j in matched composite baseline i; value between 0 and 1 (dimensionless)

T	=	Critical value of a student's t distribution for significance level α = 0.05 (i.e., 1 – α = 95% confidence interval)
$\overline{ER_t}$	=	Mean GHG emission reductions in year t (t CO_2e)
$\overline{CR_t}$	=	Mean carbon dioxide removals in year t (t CO_2e)
n	=	Number of sample units for which stock change values are available in both the project and baseline scenarios
c	=	Total number of unique constituent baseline plots j

Note that in Equation (32), only sample units i for which calculated stock change values at time t are available for both the project and baseline scenarios are included (i.e., two measurement events must have taken place in a sample unit and all of its matched constituent control plots before a paired sample i is included in the calculation of net GHG emission reductions).[11]

8.6 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 which must 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 change in carbon stocks (see the most recent version of the *VCS Standard*):[12]

$$Bu_{CR,t} = I(\Delta CO2_{wp}) \times A_t \times \frac{1}{n} \times \sum_{i=1}^{n} (MAX(0, \Delta CO2_{wp,i,t}) - MAX(0, \Delta CO2_{bsl,i,t})) \times NPR\% \quad (33)$$

Where:

$I(\Delta CO2_{wp}) = 1$ if $\sum_{i=1}^{n} \sum_{j=1}^{t} \Delta CO2_{wp,i,j} > 0$ and;

$I(\Delta CO2_{wp}) = 0$ if $\sum_{i=1}^{n} \sum_{j=1}^{t} \Delta CO2_{wp,i,j} \leq 0$

$Bu_{CR,t}$	=	Buffer credits to be deducted from removals in year t (t CO_2e)
A_t	=	Project area in year t (unit area)
n	=	Number of sample units in which stock change values are available for both the project and baseline scenarios
$\Delta CO2_{wp,i,t}$	=	Average annual carbon stock change in the project scenario in sample unit i in the monitoring interval ending at time t (t CO2e/unit area/year)

[11] The aggregated uncertainty calculation presented in Equation (32) inherently reflects the uncertainties of individual input parameters – such as carbon stock change, area, and plot-level measurements – provided that standardized measurement protocols are properly applied. This ensures that overall uncertainty captures the combined effect of component-level variability, supporting robust and conservative quantification of baseline emissions or removals.

[12] Section 3.15.16 from *VCS Standard, v4.7*

$\Delta CO2_{bsl,i,t}$	=	Carbon stock change in the baseline scenario in composite baseline *i* in year *t* (t CO_2e/unit area/year)
NPR%	=	Overall project non-permanence risk rating converted to a percentage

$$Bu_{ER,t} = I(\Delta CO2_{wp}) \times A_t \times \frac{1}{n} \times \sum_{i=1}^{n} (MAX(0, \Delta CO2_{wp,i,t}) - MAX(0, \Delta CO2_{bsl,i,t})) \times NPR\% + (1 - I(\Delta CO2_{wp})) \times A_t \times \frac{1}{n} \times \sum_{i=1}^{n} (MIN(0, \Delta CO2_{wp,i,t}) - MIN(0, \Delta CO2_{bsl,i,t}) + MAX(0, \Delta CO2_{wp,i,t}) - MAX(0, \Delta CO2_{bsl,i,t})) \times NPR\% \quad (34)$$

Where:

$I(\Delta CO2_{wp}) = 1$ if $\sum_{i=1}^{n} \sum_{j=1}^{t} \Delta CO2_{wp,i,j} > 0$ and;

$I(\Delta CO2_{wp}) = 0$ if $\sum_{i=1}^{n} \sum_{j=1}^{t} \Delta CO2_{wp,i,j} \leq 0$

$Bu_{ER,t}$	=	Buffer credits to be deducted from reductions in year *t* (t CO_2e)
A_t	=	Project area in year *t* (unit area)
n	=	Number of sample units in which stock change values are available for both the project and baseline scenarios
$\Delta CO2_{wp,i,t}$	=	Average annual carbon stock change in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO2e/unit area/year)
$\Delta CO2_{bsl,i,t}$	=	Carbon stock change in the baseline scenario in composite baseline *i* in year *t* (t CO_2e/unit area/year)
NPR%	=	Overall project non-permanence risk rating converted to a percentage (percent)

$$VCU_{CR,t} = CR_t - Bu_{CR,t} \quad (35)$$

Where:

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

$$VCU_{ER,t} = ER_t - Bu_{ER,t} \quad (36)$$

Where:

$VCU_{ER,t}$	=	Number of Verified Carbon Units, in year *t*, that result from project activities leading to reductions

ER_t	=	Net GHG emission reductions in year *t* (t CO_2e)
$Bu_{ER,t}$	=	Buffer credits to be deducted from reductions in year *t* (t CO_2e)

9 MONITORING

9.1 Data and Parameters Available at Validation

Data/Parameter	A_t
Data unit	Unit area
Description	Project area at time *t*
Equations	(1), (2), (25), (26), (27)
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-registered referencing corner points, clear landmarks, or other intersection points.
Purpose of data	Reference for other area measures
Comments	None

Data/Parameter	$W_{bsl,i,j}$
Data unit	Dimensionless
Description	Weight of constituent baseline plot *j* in matched composite baseline *i*
Equations	(6), (7), (8), (12), (25), (32)
Source of data	Derived following procedures in Appendices 1 and 2
Value applied	Between 0 and 1

Justification of choice of data or description of measurement methods and procedures applied	Weights are derived to produce an optimal match to the paired project sample unit in terms of one or more specified initial condition covariates.
Purpose of data	Calculation of baseline emissions
Comments	Weight for each constituent baseline plot is determined at t = 0 and fixed throughout the crediting period, except where a constituent baseline plot has become invalid (e.g., where a unit is now located within a registered GHG mitigation project area, or where it has not been re-measured in >10 years; see Section 6), in which case all weights in the respective composite baseline are recalculated to sum to 1, retaining the relative weights of the remaining constituent plots.

Data/Parameter	$SF_{saw,wt}$ $SF_{pulp,wt}$
Data unit	Dimensionless
Description	$SF_{saw,wt}$: Saw log 100-year average storage factor (mass remaining stored in use and landfills over 100 years) for wood type *wt* (conifers, sfw, or broadleaves, hwd) $SF_{pulp,wt}$: Pulpwood 100-year average storage factor (mass remaining stored in use and landfills over 100 years) for wood type (sfw or hwd)
Equations	(9)
Source of data	a) For projects in the United States: Table 6-A-5 in Hoover, C., R. Birdsey, B. Goines, et al. 2014. "Quantifying Greenhouse Gas Sources and Sinks in Managed Forest Systems." In *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory*. Technical Bulletin Number 1939, edited by M. Eve, D. Pape, M. Flugge, R. Steele, D. Man, M. Riley-Gilbert, and S. Biggar. USDA Office of the Chief Economist.[13]

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

Value applied	For projects in the United States:

US region and timber type	SF_{saw} Saw log mass remaining stored in use and landfills after 100 years	SF_{pulp} Pulpwood mass remaining stored in use and landfills after 100 years
Northeast softwood	0.402	0.136
Northeast hardwood	0.437	0.323
North Central softwood	0.442	0.138
North Central hardwood	0.411	0.370
Pacific Northwest (east) softwood	0.415	0.415
Pacific Northwest (west) softwood	0.511	0.119
Pacific Northwest (west) hardwood	0.284	0.284
Pacific Southwest softwood	0.444	0.444
Rocky Mountain softwood	0.463	0.463
Southeast softwood	0.423	0.191
Southeast hardwood	0.417	0.242
South Central softwood	0.415	0.215
South Central hardwood	0.393	0.229
Other West hardwood	0.357	0.357

b) For projects outside the United States: derive $SF_{saw,wt}$ and $SF_{pulp,wt}$ using national data where available (consistent with the host country's National Greenhouse Gas Inventory). If national data are unavailable, parameters may be derived from other relevant published sources (e.g., Winjum et al. 1998[14]; 2019 IPCC Refinement to the 2006 Guidelines, Vol. 4 (AFOLU), Ch. 12: Harvested Wood Products.[15]

[14] 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.

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

Justification of choice of data or description of measurement methods and procedures applied	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 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	For US-based projects, regions are defined in Hoover et al. (2014)[16]. Outside of the United States, derive parameters using national data where available (consistent with the host country's National Greenhouse Gas Inventory). If national data are unavailable, parameters may be derived from other relevant published sources (e.g., Winjum et al. 1998; 2019 IPCC Refinement to the 2006 Guidelines, Vol. 4 (AFOLU), Ch. 12: Harvested Wood Products.

Data/Parameter	GWP_g
Data unit	Dimensionless
Description	Global warming potential of gas *g*
Equations	(10)
Source of data	As set out in the most recent version of the *VCS Standard*
Value applied	See the most recent version of the *VCS Standard.*
Justification of choice of data or description of measurement methods and procedures applied	Unless otherwise directed by the VCS Program, the most recent version of the *VCS Standard* requires that CH_4 and N_2O must be converted to CO_2e using the 100-year global warming potential derived from the IPCC Fourth Assessment Report.
Purpose of data	Calculation of baseline and project emissions

[16] https://research.fs.usda.gov/treesearch/46322

Comments	None

Data/Parameter	C_f
Data unit	Proportion of pre-fire fuel biomass consumed
Description	Combustion factor
Equations	(10)
Source of data	Table 3A.1.12 in IPCC (2003). *Good Practice Guidance for Land Use, Land-use Change and Forestry*[17]
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	(10)
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

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

Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	$EF_{Ndirect}$
Data unit	t N_2O-N/t N applied
Description	Emission factor for direct nitrous oxide emissions from nitrogen additions from synthetic fertilizers, organic amendments, and crop residues
Equations	(17)
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*[18]
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	Emission factor applicable to N additions from mineral fertilizers, organic amendments, and crop residues

Data/Parameter	$Frac_{GASF}$
Data unit	Dimensionless
Description	Fraction of all synthetic nitrogen added to soils that volatilizes as ammonia and NO_x
Equations	(21)
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	0.1
Justification of choice of data or description of	See source of data

[18] Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

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 nitrogen added to soils that volatilizes as ammonia and NO_x
Equations	(21)
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	0.3
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 nitrogen on soils and water surfaces
Equations	(21)
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	See source of data

measurement methods and procedures applied	
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	$Frac_{LEACH}$
Data unit	Dimensionless
Description	Fraction of nitrogen (synthetic or organic) added to soils that is lost through leaching and runoff, in regions where leaching and runoff occurs
Equations	(22)
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	0.3
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	(22)
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	0.0075
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

9.2 Data and Parameters Monitored

Data/Parameter	$X_{bsl,i,j,t}$ $X_{wp,i,t}$
Data unit	Years
Description	Length of measurement interval ending at time *t* for constituent baseline plot *ij* Length of measurement interval ending at time *t* for sample unit *i* in the project scenario
Equations	(3), (4), (5), (13), (14), (15)
Source of data	Monitored
Description of measurement methods and procedures to be applied	N/A
Frequency of monitoring/recording	Subject to measurement interval of baseline and project plots
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project and baseline emissions
Calculation method	N/A
Comments	None

Data/Parameter	$LAG_{bsl,i,j,t}$ $LAG_{wp,i,t}$
Data unit	t CO_2e/unit area

Description	Live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* of composite baseline *i* at time *t* Live aboveground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t*
Equations	(3), (10), (13)
Source of data	Measured in project area
Description of measurement methods and procedures to be applied	Live aboveground biomass must be measured through plot-based sampling. While the general principles governing sampling design, representativeness, and measurement quality apply to all projects, the specific procedures for estimating biomass depend on the country in which the project is located and the corresponding national forest inventory (NFI). To ensure consistency and compatibility with the dynamic baseline, projects must align their biomass estimation methods with the approaches defined in the applicable NFI framework. Detailed procedures for projects located within the United States and outside the United States are provided below. Regardless of location, sampling must adhere to best practices in sample plot design, including the establishment of a minimum number of plots per primary sampling unit, determined as a function of project area and heterogeneity. Stratification should be used to capture variation in forest types, site productivity, disturbance history, and management regimes. The sampling design must be capable of supporting robust estimates across all strata, with justification provided for plot allocation and design choices to ensure transparency and reproducibility. In general, sample measurements must: • be demonstrated to be unbiased and derived from representative sampling. • adhere to best practices and QA/QC procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection) to ensure accuracy. • apply fixed diameter at breast height (dbh) and any other size thresholds. • 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. US-based projects: Aboveground biomass of each sampled tree is estimated using published allometric models from Westfall, J.A. et al. 2024. *A national-scale tree volume, biomass and carbon modeling system for the United States*. https://www.fs.usda.gov/sites/default/files/fs_media/fs_document/biomass-modeling-system.pdf). Other alternatives are Jenkins et al. (2003) or stem volume-referenced component ratio methods per Woodall et al. (2011) applied to one or more measured tree attributes, minimally including dbh.

Where using component ratio methods, stem volumes must be estimated by applying published volume equations (in the United States, using equations included in the USFS National Volume Estimator Library, NVEL[19]) specific to species, genus, or family, in descending order of preference, as available.

Non-US-based projects: estimates of live aboveground biomass must follow the measurement, estimation, and reporting procedures established by the relevant National Forest Inventory (NFI), where such procedures exist. When an NFI provides official allometric equations or volume-to-biomass conversion methods, project proponents must use those methods without modification to ensure methodological consistency with the composite baseline. Where an NFI does not publish official guidance for aboveground biomass estimation, project proponents may apply allometric equations provided they meet minimum scientific standards:

1) equations must be developed from datasets comprising at least 30 destructively sampled trees and include a range of predictive variables (e.g., DBH, height, species, wood density).
2) Regressions must be statistically significant and have coefficients of determination (r^2) ≥ 0.8.
3) Allometric equations must be selected according to the following strict order of preference. Progression to the next tier is permitted only when no equation exists in the higher tier or when the available equations fail to meet the minimum scientific criteria (≥30 trees, multi-variable models, $r^2 \geq 0.8$, and documented destructive sampling):
    a) **National species-specific equations**
    Equations developed using destructive sampling of *the same species* within the project's host country, regardless of forest type. Only equations meeting the minimum statistical standards are eligible.
    b) **National genus- or family-specific equations**
    Applicable when no species-specific equations exist. Must be based on destructive sampling conducted within the host country. Genus- and family-level equations may be applied across forest types only when explicitly validated by the source.
    c) **Biogeographical-domain species-specific equations**
    When no national equations are available, equations may be sourced from countries within the same biogeographical realm (e.g., Neotropics, Afrotropics, Palearctic), Use is permitted only when ecological conditions (precipitation regime, temperature zone, life zone) are demonstrably comparable and justified in the PD.
    d) **Biogeographical-domain genus- or family-specific equations**
    Acceptable only when Tier 3 species-specific equations are not available and when ecological comparability can be demonstrated.
    e) **National forest-type-specific equations**
    Applicable only when Tiers 1–4 do not provide usable equations. Equations must originate from destructive sampling conducted within the same country and must correspond to the forest type found within the project area.

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

f) **Biogeographical-domain forest-type-specific equations**
Permitted only when national equivalents do not exist and when the forest type classification (e.g., dry tropical forest, lower montane forest, boreal conifer forest) can be matched credibly across countries using established ecoregion frameworks (e.g., Olson et al., WWF).

g) **Authoritative broad forest-type equations (global sources)**
Forest type-specific such as those provided Tables 4.A.1 to 4.A.3 of the GPG-LULUCF (IPCC 2003); or Chave et al. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees; Global Change Biology 20 (10): 3177-3190. Other guidance documents on allometric equations:
   i) Picard N., Saint-André L., Henry M. (2012). Manual for building tree volume and biomass allometric equations: from field measurement to prediction. Food and Agricultural Organization of the United Nations, Rome, and Centre de Coopération Internationale en Recherche Agronomique pour le Développement, Montpellier, 215 pp
   ii) Walker, S., Murray, L., Tepe, T. (2016). Allometric Equation Evaluation Guidance Document. Winrock International. 75 p.
   iii) Picard, N., Fonton, N., Boyemba Bosela, F., Fayolle, A., Loumeto, J., Ngua Ayecaba, G., Sonké, B., Yongo Bombo, O. D., Maïdou, H. M., and Ngomanda, A (2025). Selecting allometric equations to estimate forest biomass from plot- rather than individual-level predictive performance, Biogeosciences, 22, 1413–1426, https://doi.org/10.5194/bg-22-1413-2025, 2025.

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.[20] Hence it is acceptable practice to use equations developed for regional forest types, provided that their accuracy has been validated with direct site-specific data following guidance given below. If a forest-type specific equation is used, it should not be used in combination with species-specific equation(s) (i.e., it must be used for all tree species[21]). 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)[22]

[20] 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)

[21] 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.

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

	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: • Kershaw Jr, J. A., M. J. Ducey, T. W. Beers, and B. Husch. 2016. *Forest Mensuration*. John Wiley & Sons. • Avery, T. E., and H. E. Burkhart. 2015. *Forest Measurements*. Waveland Press. • US Forest Service Department of Agriculture. 2019. *Field Data Collection Procedures for Phase 2 Plots*. Forest Inventory and Analysis National Core Field Guide.[23] Carbon is calculated from biomass by applying a carbon fraction of 0.47, and carbon dioxide equivalent (CO_2e) is calculated from carbon applying the factor 44/12.
Frequency of monitoring/recording	Initial measurement at time t = 0 must not be older than ten (10) years prior to t = 0 or the most recent remeasurement date of the applicable baseline plots, whichever period is shorter. Thereafter, biomass-related parameters must be remeasured at least every five (5) years in the project scenario and at least every ten (10) years in the baseline scenario, or more frequently where applicable.
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project and baseline emissions. Derivation of $BBremoved_{saw}$ and $BBremoved_{pulp}$ parameters
Calculation method	See description of measurement methods and procedures to be applied
Comments	None

Data/Parameter	$LBG_{bsl,i,j,t}$ $LBG_{wp,i,t}$
Data unit	t CO_2e/unit area
Description	Live belowground biomass stocks in the baseline scenario at constituent baseline plot *j* of composite baseline *i* at time *t* Live belowground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t*
Equations	(4) (14)

[23] Available at: https://www.fia.fs.usda.gov/library/field-guides-methods-proc/docs/2022/core_ver9-2_9_2022_SW_HW%20table_rev_12_13_2022.pdf

Source of data	Measured in project area
Description of measurement methods and procedures to be applied	Similar to Live aboveground biomass, the specific procedures for estimating belowground biomass depend on the country in which the project is located and the corresponding national forest inventory (NFI). To ensure consistency and compatibility with the dynamic baseline, projects must align their biomass estimation methods with the approaches defined in the applicable NFI framework where such procedures exist. Detailed procedures for projects located within the United States and outside the United States are provided below. Live belowground biomass is estimated via component ratio methods (e.g., root to shoot ratios) applied to direct measurements from plot-based sampling. Stratification (either pre-sampling or post-stratification) is an accepted method to improve precision in ground-based forest sampling (Cochran, 1977). Project proponents must assess the need for stratification based on forest heterogeneity within the project area. Where stratification is not applied, the proponent must provide justification that sampling precision requirements are met without it. Where stratification is applied, equations must be implemented at the stratum level and aggregated to the project level using area-weighted estimates. Sample measurements must: 1) be demonstrated to be unbiased and derived from representative sampling. 2) adhere to best practices and QA/QC procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection) to ensure accuracy. 3) apply fixed dbh and any other size thresholds. In the United States: Belowground biomass of each sampled tree is estimated using published allometric models from Westfall, J.A. et al. 2024 or published component ratios from Jenkins et al. (2003). Non-US-based projects: estimates of live belowground biomass must follow the measurement, estimation, and reporting procedures established by the relevant National Forest Inventory (NFI), where such procedures exist. 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 or other sources (see list below). In 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).[24] The selected ratios must reflect species and stand characteristics to the extent possible, and their application must be transparently documented to ensure

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

	consistency, reproducibility, and alignment with international good practice. Other sources to derive ecoregion-based root to shoot ratios at global scale: • Huang et al. 2021. A global map of root biomass across the world's forests. Earth Syst. Sci. Data, 13, 4263–4274, https://doi.org/10.5194/essd-13-4263-2021, 2021. • Ye et al. 2021. Spatial patterns of global-scale forest root-shoot ratio and their controlling factors. Science of The Total Environment 800, 15, 149251 https://doi.org/10.1016/j.scitotenv.2021.149251 • Ma, H., Mo, L., Crowther, T.W. et al. The global distribution and environmental drivers of aboveground versus belowground plant biomass. Nat Ecol Evol 5, 1110–1122 (2021). https://doi.org/10.1038/s41559-021-01485-1 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: Kershaw Jr, J. A., M. J. Ducey, T. W. Beers, and B. Husch. 2016. *Forest Mensuration*. John Wiley & Sons. Avery, T. E., and H. E. Burkhart. 2015. *Forest Measurements*. Waveland Press. US Forest Service Department of Agriculture. 2019. *Field Data Collection Procedures for Phase 2 Plots*. Forest Inventory and Analysis National Core Field Guide. 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. Carbon is calculated from biomass by applying a carbon fraction of 0.47, and carbon dioxide equivalent (CO_2e) is calculated from carbon applying the factor 44/12.
Frequency of monitoring/recording	Initial measurement at time t = 0 must not be older than ten (10) years prior to t = 0 or the most recent remeasurement date of the applicable baseline plots, whichever period is shorter. Thereafter, biomass-related parameters must be remeasured at least every five (5) years in the project scenario and at least every ten (10) years in the baseline scenario, or more frequently where applicable
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project and baseline emissions. Derivation of $BBremoved_{saw}$ and $BBremoved_{pulp}$ parameters.
Calculation method	See description of measurement methods and procedures to be applied
Comments	None

Data/Parameter	$DW_{bsl,i,j,t}$ $DW_{wp,i,t}$
Data unit	t CO_2e/unit area
Description	Dead wood biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* Dead wood biomass stocks in the baseline scenario in constituent baseline plot *j* of composite baseline *i* at time *t*
Equations	(5), (10) (15)
Source of data	Field measurements
Description of measurement methods and procedures to be applied	Standing dead wood is required. Lying dead wood may be included only where it is possible to account for it in both the project and baseline scenarios (i.e., lying dead wood must be included in the national forest inventory data used for the composite baseline)[25]. Estimates of dead wood biomass must follow the measurement, estimation, and reporting procedures established by the relevant National Forest Inventory (NFI), where such procedures exist. Standing dead wood is sampled via plot-based forest inventory methods, and lying dead wood via line intersect sampling,[26] perpendicular distance sampling,[27] or other unbiased approaches. Specific sample designs/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: 1) be demonstrated to be unbiased and derived from representative sampling.

[25] For the purposes of this methodology, lying dead wood does not include short-term harvest residues (logging slash) generated during timber operations, which are accounted for under harvest emissions and wood products where applicable.

[26] Warren, W. G., and P. F. Olsen. 1964. “A Line Intersect Technique for Assessing Logging Waste.” *Forest Science* 10 (3): 267–76.

Van Wagner, C. E. 1968. “The Line Intersect Method in Forest Fuel Sampling.” *Forest Science* 14 (1): 20–6.

[27] Williams, M. S., and J. H. Gove. 2003. “Perpendicular Distance Sampling: An Alternative Method for Sampling Downed Coarse Woody Debris.” *Canadian Journal of Forest Research* 33 (8): 1564–79. https://doi.org/10.1139/x03-056

Williams, M. S., H. T. Valentine, J. H. Gove, and M. J. Ducey. 2005. “Additional Results for Perpendicular Distance Sampling.” *Canadian Journal of Forest Research* 35 (4): 961–6. https://doi.org/10.1139/x05-023

Ducey, M. J., M. S. Williams, J. H. Gove, S. Roberge, and R. S. Kenning. 2013. “Distance-limited Perpendicular Distance Sampling for Coarse Woody Debris: Theory and Field Results.” *Forestry* 86 (1): 119–28. https://doi.org/10.1093/forestry/cps059

2) adhere to best practices and QA/QC procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection) to ensure accuracy.
3) apply fixed size thresholds.

US-based projects: For each standing dead tree, stem volume must be estimated using published volume equations (in the United States, using equations included in the USFS National Volume Estimator Library, NVEL) specific to species, genus, or family, in descending order of preference, as available. The equations must be applied to one or more measured tree attributes, minimally including dbh and remaining stem height. Note that standing dead wood is restricted here to aboveground stem (bole) biomass.

Biomass of standing and lying dead wood must be estimated from sampled volumes using published wood densities specific to species, genus, or family, in descending order of preference, as available and density reduction factors referencing decomposition states (e.g., procedures per Harmon et al. 2011[28]).

Non-US-based projects: Where the relevant NFI provides procedures for estimating standing and lying dead wood, project proponents must apply those procedures to ensure consistency with the baseline donor plots. Where such procedures do not exist or are incomplete, details on specific guidance for data augmentation are provided in Appendix 2. As a general principle, biomass of standing and lying dead wood[29] must be estimated using internationally recognized good practice, including the 2019 Refinement to the 2006 IPCC Guidelines for AFOLU (Volume 4, Chapter 4). In these cases, dead wood biomass must be derived from sampled volumes using published wood density values specific to species, genus, or family, in descending order of preference, together with decay-class–specific density reduction factors consistent with IPCC guidance or peer-reviewed regional studies. Project proponents must document the measurement approach, decay-class system, and conversion factors used, and demonstrate that these methods can be consistently applied to both the project and baseline scenarios.

Tree attributes (e.g., dbh, total height, species, wood density) incorporated as independent variables in allometric equations must be directly measured in the field, applying established best practices such as those found in:

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

[29] Standing dead wood is a required pool. Lying dead wood may be included only where it is possible to account for it in both the project and baseline scenarios (i.e., lying dead wood must be included in the national forest inventory data used for the composite baseline)

	Kershaw Jr, J. A., M. J. Ducey, T. W. Beers, and B. Husch. 2016. *Forest Mensuration*. John Wiley & Sons. Avery, T. E., and H. E. Burkhart. 2015. *Forest Measurements*. Waveland Press. US Forest Service Department of Agriculture. 2019. *Field Data Collection Procedures for Phase 2 Plots*. Forest Inventory and Analysis National Core Field Guide. 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. Carbon is calculated from biomass by applying a carbon fraction of 0.47, and carbon dioxide equivalent (CO_2e) calculated from carbon applying the factor 44/12.
Frequency of monitoring/recording	Initial measurement at time t = 0 must not be older than ten (10) years prior to t = 0 or the most recent remeasurement date of the applicable baseline plots, whichever period is shorter. Thereafter, biomass-related parameters must be remeasured at least every five (5) years in the project scenario and at least every ten (10) years in the baseline scenario, or more frequently where applicable
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project and baseline emissions
Calculation method	See description of measurement methods and procedures to be applied
Comments	None

Data/Parameter	$BBremoved_{saw,wt,bsl,i,j,t}$ $BBremoved_{saw,wt,wp,i,t}$
Data unit	t CO_2e/unit area
Description	Saw log bole biomass stocks in wood type *wt* (*wt* = conifer, sfw or broadleaves, hwd) in commercial species removed in the baseline scenario in constituent baseline plot *j* of composite baseline *i* in the monitoring interval ending at time *t* Saw log bole biomass stocks in wood type *wt* (*wt* = conifer, sfw or broadleaves, hwd) in commercial species removed in the project scenario in sample unit *i* in the monitoring interval ending at time *t*
Equations	(9)
Source of data	Field measurements from permanent plots subject to harvest in the monitoring interval ending at time *t*

Description of measurement methods and procedures to be applied	US-based projects: Saw logs will be distinguished from pulpwood on the basis of dbh: 1) Conifer (softwood) saw logs are from trees with at least 22.9 cm (9 in) dbh. 2) Broadleaf (hardwood) saw logs are from trees with at least 27.9 cm (11 in) dbh. 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* (i.e., $LAG_{i,t-x}$), 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 USFS National Volume Estimator Library, NVEL) and wood densities (specific to species, genus, or family, in descending order of preference, as available). **Approach 2 – Estimate aboveground biomass using the National Scale Volume and Biomass Estimators (NSVB)** Bole biomass of each sampled tree is estimated using published allometric models from Westfall, J.A. et al. 2024. *A national-scale tree volume, biomass and carbon modeling system for the United States*. https://www.fs.usda.gov/sites/default/files/fs_media/fs_document/biomass-modeling-system.pdf). **Approach 3: Estimate aboveground 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 United States, using Jenkins et al. (2003) for stem component ratios and total aboveground biomass equations). Note that these parameters are restricted to commercial species. In the United States, commercial species are defined as those not from species groups 23, 43, or 48 (see FIA Database User Guide Appendix E).[30] Non-US-based projects: 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

[30] Available at: https://www.fia.fs.usda.gov/library/database-documentation/current/ver91/FIADB%20User%20Guide%20P2_9-1_final.pdf

	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. 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. Tree attributes (e.g., dbh, total height, species, wood density) incorporated as independent variables in allometric equations must be directly measured in the field applying established best practices, such as those found in: • Kershaw Jr, J. A., M. J. Ducey, T. W. Beers, and B. Husch. 2016. *Forest Mensuration*. John Wiley & Sons. • Avery, T. E., and H. E. Burkhart. 2015. *Forest Measurements*. Waveland Press. • US Forest Service Department of Agriculture. 2019. *Field Data Collection Procedures for Phase 2 Plots.* Forest Inventory and Analysis National Core Field Guide. Carbon is calculated from biomass by applying a carbon fraction of 0.47, and carbon dioxide equivalent (CO_2e) is calculated from carbon applying the factor 44/12.
Frequency of monitoring/recording	Initial measurement at time t = 0 must not be older than ten (10) years prior to t = 0 or the most recent remeasurement date of the applicable baseline plots, whichever period is shorter. Thereafter, biomass-related parameters must be remeasured at least every five (5) years in the project scenario and at least every ten (10) years in the baseline scenario, or more frequently where applicable
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project and baseline emissions
Calculation method	See description of measurement methods and procedures to be applied
Comments	None

Data/Parameter	$BBremoved_{pulp,wt,bsl,i,j,t}$ $BBremoved_{pulp,wt,wp,i,t}$
Data unit	t CO_2e/unit area
Description	Pulpwood bole biomass stocks in wood type *wt* (*wt* = conifer, sfw or broadleaves, hwd) in commercial species removed in the baseline scenario at constituent baseline plot *j* of composite baseline *i* in the monitoring interval ending at time *t*

	Pulpwood bole biomass stocks in wood type *wt* (*wt* = conifer, sfw or broadleaves, hwd) in commercial species removed in the project scenario in sample unit *i* in the monitoring interval ending at time *t*
Equations	(9)
Source of data	Field measurements from permanent plots subject to harvest in the monitoring interval ending at time *t*
Description of measurement methods and procedures to be applied	US-based projects: Pulpwood logs are distinguished from saw logs on the basis of diameter at breast height: 1) Softwood pulpwood is from trees with 12.7 to 22.8 cm (5.0 to 8.9 in) dbh. 2) 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., $LAG_{i,t-x}$), 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 USFS National Volume Estimator Library, NVEL) and wood densities (specific to species, genus, or family, in descending order of preference, as available). **Approach 2 – Estimate aboveground biomass using the National Scale Volume and Biomass Estimators (NSVB)** Bole biomass of each sampled tree is estimated using published allometric models from Westfall, J.A. et al. 2024. *A national-scale tree volume, biomass and carbon modeling system for the United States*. https://www.fs.usda.gov/sites/default/files/fs_media/fs_document/biomass-modeling-system.pdf). **Approach 3: Estimate aboveground 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 United States using Jenkins et al. (2003) for stem component ratios and total aboveground biomass equations). Note that these parameters are restricted to commercial species. In the United States, commercial species are defined as those not from species groups 23, 43, or 48 (see FIA Database User Guide Appendix E[31]). Non-US-based projects: the classification and estimation of pulpwood 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

[31] Available at: https://www.fia.fs.usda.gov/library/database-documentation/current/ver91/FIADB%20User%20Guide%20P2_9-1_final.pdf

	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. 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. 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: • Kershaw Jr, J. A., M. J. Ducey, T. W. Beers, and B. Husch. 2016. *Forest Mensuration*. John Wiley & Sons. • Avery, T. E., and H. E. Burkhart. 2015. *Forest Measurements*. Waveland Press. • US Forest Service Department of Agriculture. 2019. *Field Data Collection Procedures for Phase 2 Plots.* Forest Inventory and Analysis National Core Field Guide. Carbon is calculated from biomass by applying a carbon fraction of 0.47, and carbon dioxide equivalent (CO_2e) is calculated from carbon applying the factor 44/12.
Frequency of monitoring/recording	Initial measurement at time t = 0 must not be older than ten (10) years prior to t = 0 or the most recent remeasurement date of the applicable baseline plots, whichever period is shorter. Thereafter, biomass-related parameters must be remeasured at least every five (5) years in the project scenario and at least every ten (10) years in the baseline scenario, or more frequently where applicable
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project and baseline emissions
Calculation method	See description of measurement methods and procedures to be applied
Comments	None

Data/Parameter	$M_{wp,SF,i,t}$
Data unit	t fertilizer/unit area

Description	Mass of project nitrogen-containing synthetic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t*
Equations	(18)
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	See source of data
Frequency of monitoring/recording	Initial measurement at or preceding time t = 0 and to be re-measured every 5 years or more frequently in the project
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	None

Data/Parameter	$NC_{wp,SF,i,t}$
Data unit	t N/t fertilizer
Description	Nitrogen content of project synthetic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t*
Equations	(18)
Source of data	N content is determined following fertilizer manufacturer's specifications.
Description of measurement methods and procedures to be applied	See source of data
Frequency of monitoring/recording	Initial measurement at or preceding time t = 0 and to be re-measured every 5 years or more frequently in the project

QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	None

Data/Parameter	$M_{wp,OF,i,t}$
Data unit	t fertilizer/unit area
Description	Mass of project nitrogen-containing organic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t*
Equations	(19)
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	See source of data
Frequency of monitoring/recording	Initial measurement at or preceding time t = 0 and to be re-measured every 5 years or more frequently in the project
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	None

Data/Parameter	$NC_{wp,OF,i,t}$
Data unit	t N/t fertilizer
Description	Nitrogen content of project organic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t*

Equations	(19)
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 or preceding time t = 0 and to be re-measured every 5 years or more frequently in the project
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	None

Data/Parameter	$LTremoved_{bsl,i,j,t}$ $LTremoved_{wp,i,t}$
Data unit	t CO_2e/unit area
Description	Live tree biomass stocks removed in the baseline scenario at constituent baseline plot *j* in composite baseline *i* subject to harvest in the monitoring interval ending at time *t* Live tree biomass stocks removed in the project scenario in sample unit *i* subject to harvest in the monitoring interval ending at time *t*
Equations	(25)
Source of data	Measured on permanent sample plots in project area and on without-treatment (baseline) sites respectively
Description of measurement methods and procedures to be applied	Includes pre-existing live tree above- and belowground biomass that is killed, removed, or emitted on plots subject to harvest. Estimated via pre- and post-harvest cruises as: $LTremoved_{\bullet,i,t} = (LAG_{\bullet,i,t} - LAG_{\bullet,i,t-x}) + (LBG_{\bullet,i,t} - LBG_{\bullet,i,t-x})$ Where:

	$LTremoved_{\bullet,i,t}$ — Live tree biomass stocks removed in scenario • (with or without project activity) in sample unit *i* (or constituent sample *j* in composite baseline *i*) subject to harvest in the monitoring interval ending at time *t* (t CO_2e/unit area) $LAG_{\bullet,i,t}$ — Live aboveground biomass stocks in scenario • (with or without project activity) in sample unit *i* (or constituent sample *j* in composite baseline *i*), subject to harvest in the monitoring interval ending at time *t*, measured at time *t* (t CO_2e/unit area) $LAG_{\bullet,i,t-x}$ — Live aboveground biomass stocks in scenario • (with or without project activity) in sample unit *i* (or constituent sample *j* in composite baseline *i*) subject to harvest in the monitoring interval ending at time *t*, measured at time $t-x$ where $t-x$ is the time of the most recent measurement preceding the harvest (t CO_2e/unit area) $LBG_{\bullet,i,t}$ — Live belowground biomass stocks in scenario • (with or without project activity) in sample unit *i* (or constituent sample *j* in composite baseline *i*) subject to harvest in the monitoring interval ending at time *t*, measured at time *t* (t CO_2e/unit area) $LBG_{\bullet,i,t-x}$ — Live belowground biomass stocks in scenario • (with or without project activity) in sample unit *i* (or constituent sample *j* in composite baseline *i*) subject to harvest in the monitoring interval ending at time *t*, measured at time $t-x$, where $t-x$ is the time of the most recent measurement preceding the harvest (t CO_2e/unit area) Where harvest does not occur in a given sample unit *i* or *j* in the monitoring interval ending at time *t*, $LTremoved_{wp,i,t}$ and $LTremoved_{bsl,i,j,t}$ are set to zero.
Frequency of monitoring/recording	Initial measurement at or preceding time $t = 0$ and to be re-measured every 5 years or more frequently in the project and every 10 years or more frequently in the baseline
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of leakage
Calculation method	Description of measurement methods and procedures to be applied
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 sample units and constituent baseline plots (located outside of the project area). Monitored stock parameters are collected and recorded at the sample unit scale, and emission reductions 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) The project proponent must monitor changes in hydrology and soil disturbance attributable to project activities at each monitoring event to demonstrate that such changes do not exceed 10% of the project area.
4) 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;
5) Data to be collected and data collection techniques, documented in a standard operating procedure for field data collection. Sample designs must be specified (clearly delineate the sample population spatially, and justify sampling intensities, and selection of sample units and sampling stages, where applicable) and unbiased estimators of population parameters identified, which will be applied in calculations;
6) Anticipated frequency of monitoring;
7) QA/QC procedures to ensure accurate data collection and to screen for, and where necessary, correct anomalous values, ensure completeness, perform independent checks on analysis results, and other safeguards as appropriate;
8) Data archiving procedures, including procedures for any anticipated updates to electronic file formats. All data collected as 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;
9) Roles, responsibilities, and capacity for monitoring team and management.

As part of monitoring, project proponents must describe the 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, to demonstrate alignment between project implementation and the methodology's statistical framework.

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.

Composite baseline

A database must be maintained detailing constituent baseline plots and their respective weights (derived at t = 0), with unique identifiers ascribed to each composite baseline, its constituent baseline plots, and all trees in those plots. The monitoring plan must specify the schedule and procedures for periodically acquiring, archiving, and processing re-measurement data from the constituent plots.

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APPENDIX 1: PERFORMANCE METHOD – UNITED STATES

A1.1 Introduction

This appendix must be used in tandem with the main methodology body for all projects located in the United States. The appendix focuses on a step-by-step process for developing a composite baseline using US Forest Service Forest Inventory and Analysis (FIA) data. All steps included in this appendix must be considered a requirement of the methodology unless explicitly labeled as optional.

A1.2 Applicability Conditions

This appendix is applicable where both of the following conditions are met:

1) The project activity meets all applicability conditions set out in Section 4 of the methodology.
2) The project area is located within the United States for which data from the U.S. Forest Inventory and Analysis (FIA) program are available and applicable.

A1.3 Baseline Scenario

The baseline scenario is represented by business-as-usual practice on US Forest Service (USFS) Forest Inventory and Analysis (FIA) inventory plots matched to specific project sample units.[32] FIA inventory plots are an appropriate source for establishing business-as-usual practices in the US, selected via representative sampling at a national scale and meeting all other requirements specified in Section 6 of the methodology. Selection of appropriately matched FIA inventory plots is ensured through requirements regarding donor pool selection (see Section A1.5).

Note that application of the performance benchmark effectively excludes, based on comparative outcomes, crediting of project activities that may be expected to be implemented without carbon incentives. It also ensures that credited projects produce performance improvements relative to the business-as-usual case (represented by the crediting baseline). The most plausible baseline scenario is defined by the level of carbon stock change observed in the matched control (without carbon finance) plots. For example:

[32] The measurement frequency of control plots in *VM0045* is currently constrained by the availability of FIA sampling data. The FIA program collects and updates forest inventory data on a rolling basis via a rotating panel design (Bechtold and Patterson 2005), where a fraction of the total plots is measured each year, ensuring a steady stream of updated data. The data are collected continuously, measuring a subset (~10–20%) of total plots each year. This means that full forest inventories are completed every 5–10 years, depending on the state or region (i.e., each FIA plot is revisited every 5–7 years in the Eastern US while in the Western US, where forest change is generally slower, plots are remeasured every 10 years) (see Appendix J in the 2024 FIA user guide). As a result, at any given time, the FIA dataset contains both newly measured plots and older measurements awaiting updates. In consequence, in this methodology, carbon stock change is annualized over the length of the measurement interval, mitigating the potential delay in reflecting changes by smoothing data over time.

- **IFM activity implementing constraints on timber harvest:** Matched control plots may be expected to witness business-as-usual timber harvests of greater magnitude and/or higher frequency than the project activity that imposes constraints on timber harvest.

- **IFM activity implementing management of competing vegetation to release natural regeneration:** Matched control plots, subject to business-as-usual minimal or no treatment of competing invasive shrubs may be expected to witness continued suppression of natural regeneration and lower tree growth than the project activity that reduces the extent of competing vegetation and releases the regenerating trees.

A1.4 Performance Benchmark

The performance benchmark is set equal to weighted average stock change measured on FIA plots matched to specific project sample units (with weighting proportional to the closeness of the match), representing business-as-usual practice. Equation (1) in the methodology derives and applies the performance benchmark for demonstration of additionality. Equation (6) derives the performance benchmark for the crediting baseline. The performance benchmarks essentially represent expected business-as-usual practice in forest stands similar to the project area. Equations (1) and (6) are dependent on periodic measurement of matched FIA plots. Procedures to match FIA plots to project sample units are provided below. Nearest-neighbor matching is an established impact evaluation approach in the environmental field[33] and has been previously applied to evaluate the impacts of incentive programs on forest management using US Forest Service National Woodland Owner Survey data.[34]

A1.5 Procedure for Developing Composite Baselines in the United States

In the United States, composite baselines (used to derive performance benchmarks for additionality and crediting baselines) must be developed primarily using data derived from the USFS FIA database. The following steps must be followed to develop matches for the population of sample units:

1) **Donor pool selection:** The donor pool for each sample unit is set by a process that involves the application of both exact matching criteria and calipers (maximum permitted difference between sample unit and individual control plots).

   a) Subset the FIA database to select eligible FIA plots. Begin with the most recent measurement of potential donor plots (i.e., exclude plots whose PLT_CN is listed as

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[33] Ferraro, P. J., and M. M. Hanauer. 2014. "Advances in Measuring the Environmental and Social Impacts of Environmental Programs." *Annual Review of Environment and Resources* 39 (1): 495–517. https://doi.org/10.1146/annurev-environ-101813-013230

[34] Song, N., F. X. Aguilar, and B. J. Butler. 2014. "Cost-share Program Participation and Family Forest Owners' Past and Intended Future Management Practices." *Forest Policy and Economics* 46: 39–46. https://doi.org/10.1016/j.forpol.2014.06.003

another plot's PREV_PLT_CN in the FIA PLOT table). Then, exclude plots that meet any of the following criteria (plots must not be excluded on the basis of any criteria other than those provided below):

i) Lacking at least two completed measurement cycles (i.e., KINDCD in FIA PLOT table is equal to 2) or lacking measurement from the most recently completed re-measurement cycle;

ii) Spanning more than one condition code (i.e., FIA COND table variable CONDPROP_UNADJ is equal to 1);

iii) Located inside of the project area (to assess the location of any FIA plot, the nearest project area boundary is buffered externally by 1.6 kilometers)

iv) Optional – Located within a registered GHG mitigation project area (where this is possible to determine;[35] to assess the location of any FIA plot, the nearest project area boundary is buffered externally by 1.6 kilometers);

v) Not of the same stand origin category as the project sample unit (i.e., STDORGCD from FIA COND table);

vi) Not of the same forest type group[36] as the project sample unit;

vii) Not within the same land ownership class (public, private) as the project sample unit;

viii) Not within the same US Forest Service ecological section[37] as the project sample unit;

ix) Optional – calipers: FIA plots may be excluded where they exceed a user-specified caliper value (an absolute value of the difference between the sample unit and FIA plot value) for one or more of the included continuous covariates (see Table A1.1). The magnitude of any calipers applied may be set by the project proponent, justified based on the expected relationship between the covariate and stock change (in the context of the IFM project activity), and number of available FIA plots (see Part b).

b) Where after donor pool selection there are fewer than 50 plots available for matching, redefine the donor pool in a stepwise fashion following the criteria below. After each

[35] Note that (iv) is optional and it is conservative to include plots located within a registered GHG mitigation project area.

[36] Forest type groups are listed in Appendix D in Burrill, E. A., G. A. Christensen, B. L. Conkling, et al. 2023. *The Forest Inventory and Analysis Database: Database Description and User Guide Version 9.1 for Phase 2*. US Department of Agriculture, Forest Service. https://www.fia.fs.usda.gov/library/database-documentation/current/ver91/FIADB%20User%20Guide%20P2_9-1_final.pdf

[37] Cleland, D. T., J. A. Freeouf, J. E. Keys, G. J. Nowacki, C. A. Carpenter, and W. H. McNab. 2007. *Ecological Subregions: Sections and Subsections for the Conterminous United States.* Gen. Tech. Report WO-76D. USDA Forest Service. https://doi.org/10.2737/WO-GTR-76D

step, assess the size of the donor pool; when it exceeds 50 plots, proceed to matching in Step 2 below.

i) Remove any calipers applied in Step (ix) above;

ii) Remove the restriction to ecological section, incorporating all FIA plots within the ecological province where that ecological section is found;

iii) Remove the restriction to ecological province, incorporating all FIA plots within the states where that ecological province is found;

2) **Optional matching datasets**: Where FIA data are demonstrably insufficient to construct a statistically valid donor pool for a defined stratum, optional matching datasets[38] may be used if all of the following conditions are met:

a) Insufficiency persists after reasonable relaxation of matching constraints consistent with the requirements for the Donor Pool selection above

b) Measurement protocols, plot design, tree inclusion thresholds, and biomass estimation methods are demonstrably harmonized with FIA definitions

c) Temporal structure is aligned with FIA measurement cycles

d) Inclusion does not materially alter the distribution of key matching covariates, as demonstrated through diagnostic testing

e) Statistical justification, including minimum effective sample size and variance diagnostics, is documented and validated by a VVB

Optional matching datasets used under this section must also meet the applicable requirements set out in Section A2.5 of Appendix 2 (Optional Matching Dataset Eligibility), to the extent relevant to the U.S. context. In cases of overlap, the requirements of this Appendix take precedence, while Appendix 2 provides additional criteria to ensure consistency, transparency, and statistical validity of supplementary datasets.

3) **Matching:** Matching applies a k-nearest neighbor optimal matching approach with replacement,[39] with *k* equal to 10. For each FIA plot in the donor pool, calculate initial condition covariates from the most recent plot measurements collected prior to project start, then calculate Mahalanobis distances relative to each project sample unit. For each project sample unit, select the 10 FIA plots with the lowest Mahalanobis distances and derive relative weights proportional to the inverse of the Mahalanobis distance, that sum to 1 (Equation (A1) below). The vector of initial condition covariates must include the covariates specified in Table A1.1. Additional

[38] An optional matching dataset is a publicly accessible, probability-based forest inventory system operating at the state, multi-state, or county level within the United States that: (a) Uses systematic or statistically representative sampling designs comparable to FIA; (b) Employs permanent or periodically remeasured plots; (c) Applies measurement protocols that can be demonstrably harmonized with FIA definitions for tree inclusion thresholds, plot design, and biomass estimation; (d) Covers a defined geographic jurisdiction relevant to the project stratum; and (e) Is independent of project proponent control.

[39] See Stuart, E. A. 2010. "Matching Methods for Causal Inference: A Review and a Look Forward." *Statistical Science* 25 (1): 1–21. https://doi.org/10.1214/09-STS313

covariates may be incorporated provided that there is a theoretically sound or empirically demonstrated basis for including them (e.g., peer-reviewed study), they are derived from direct measurements or published sources (e.g., US Census Bureau data), and minimum match quality is obtained (see below).

$$W_{bsl,i,j} = \frac{{}^{1}/_{MD_{ij}} \times 100}{\sum_{j=1}^{10} {}^{1}/_{MD_{ij}} \times 100} \quad \text{(A1)}$$

Where:

$W_{bsl,i,j}$	=	Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1 (dimensionless)
MD_{ij}	=	Mahalanobis distance of constituent baseline plot *ij* relative to project sample unit *i* (dimensionless)

Mahalanobis distance is a multivariate measure defining the "nearness" or similarity of two individuals, here a project sample unit and a FIA plot in the donor pool. The R package optmatch[40] may be used to calculate Mahalanobis distances and implement the matching approach outlined above. Calculation of Mahalanobis distance is further explained in Rosenbaum (2010)[41] and Stuart (2010)[42].

Table A1.1. Required covariates for obtaining matches of composite baselines from USFS FIA plots (see also Data and parameters available at validation for project sample unit, below)

Covariate	FIA Database Code[43]	Unit
Distance to sample (treatment/project case) unit		Kilometers
Stand age	STDAGE	Years
Site productivity class code	SITECLCD	FIA Classes 1–7 (in cubic feet/acre/year)

[40] Hansen, B. B., and S. O. Klopfer. 2006. "Optimal Full Matching and Related Designs Via Network Flows." *Journal of Computational and Graphical Statistics* 15 (3): 609–27. https://doi.org/10.1198/106186006X137047

[41] Rosenbaum, P. R. 2010. *Design of Observational Studies.* 1st ed. Springer. https://doi.org/10.1007/978-1-4419-1213-8

[42] Stuart, E. A. 2010. "Matching Methods for Causal Inference: A Review and a Look Forward." *Statistical Science* 25 (1): 1–29. https://doi.org/10.1214/09-STS313

[43] Burrill, E. A., G. A. Christensen, B. L. Conkling, et al. 2023. *The Forest Inventory and Analysis Database: Database Description and User Guide Version 9.1 for Phase 2*. US Department of Agriculture, Forest Service. https://www.fia.fs.usda.gov/library/database-documentation/current/ver91/FIADB%20User%20Guide%20P2_9-1_final.pdf

Covariate	FIA Database Code[43]	Unit
Regeneration Stocking – Total relative density per acre (Ducey and Knapp 2010[44]) of all live trees ≥1" and <5" dbh, of commercial species from FIA's SEEDLING and TREE tables. Commercial species are defined as those not from species groups 23, 43, or 48 (see FIA Database User Guide Appendix E). Relative density (RD) per acre is calculated for each individual as $RD_{per\ acre}$ = 2.47 × (0.00015 + (0.00218 × $SpecificGravity_{Species}$)) × $(dbh/10)^{1.6}$	Derived from FIA database (FIADB) data regeneration microplot and tree subplot	Dimensionless (0 to 1)
Elevation (optional)	ELEV	Feet (in 10 or 100 foot categories)
Slope	SLOPE	Percent
Commercial Stocking – Total relative density per acre (Ducey and Knapp 2010) of live trees of commercial species ≥5" dbh, with at least one sound, straight eight-foot section. Commercial species are defined as above.	Derived from FIADB data, uses TREECLCD to identify trees with requisite form characteristics	Dimensionless (0 to 1)
Quadratic mean diameter = diameter of tree with average basal area (considering only live trees ≥5" dbh)	Derived from FIADB data	Inches
Horizontal distance to improved road	RDDISTCD	Code (1 to 9)

4) **Match quality:** Match quality is assessed across the sample population of matched pairs (project sample units and matched composite baselines). For each included covariate *x*, calculate the standardized difference of means (SDM) as:

[44] Ducey, M. J., and R. A. Knapp. 2010. "A Stand Density Index for Complex Mixed Species Forests in the Northeastern United States." *Forest Ecology and Management* 260 (9): 1613–22. https://doi.org/10.1016/j.foreco.2010.08.014

$$SDM = \left|\overline{x}_{wp,x} - \overline{x}_{bsl,x}\right| \Big/ \sqrt{\left(\frac{\sigma_{wp,x}^2 + \sigma_{bsl,x}^2}{2}\right)} \quad \text{(A2)}$$

Where:

SDM	=	Standardized difference of means
$\overline{x}_{wp,x}$	=	Mean value of covariate *x* in the population of sample units representing the project scenario
$\overline{x}_{bsl,x}$	=	Mean value of weighted sum of covariate *x* in the population of matched composite baselines representing the baseline scenario
$\sigma_{wp,x}^2$	=	Sample variance of covariate *x* in the population of sample units representing the project scenario
$\sigma_{bsl,x}^2$	=	Sample variance of covariate *x* in the population of sample units representing the baseline scenario

The mean value of the weighted sum of covariate *x* in the population of matched composite baselines representing the baseline scenario is calculated as:

$$\overline{x}_{bsl,x} = \left(\frac{1}{n}\right) \times \sum_{i=1}^{n} \sum_{j=1}^{10} Covariate_{x,i,j} \times W_{bsl,i,j} \quad \text{(A3)}$$

Where:

$Covariate_{x,i,j}$	=	Value of covariate *x* for constituent baseline plot *j* in matched composite baseline *i*
$W_{bsl,i,j}$	=	Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1, derived in Equation (A1) (dimensionless)
n	=	Number of matched composite baselines

Note – Distance to sample unit (a required covariate) will necessarily be equal to 0 for all sample units. As a result, distance to sample unit must be replaced with latitude and longitude for calculation of SDMs and matching quality assessment.

Overall, match results are deemed valid where *SDM* for each covariate is less than or equal to 0.25. Where the overall match is deemed valid, component plots and their respective weights across the population of composite baselines are fixed for the duration of the crediting period. If the overall match is not deemed valid, the donor pool selection and matching steps above are repeated with progressively smaller *k* values until a valid overall match is achieved.

Table A1.2. Data and parameters available at validation for project sample units (sources of covariate values for project sample units)

Data/Parameter	Distance to sample (treatment/project case) unit
Data unit	Kilometers
Description	Distance to sample (treatment/project case) unit

Equations	N/A
Source of data	Calculated from GIS analysis of geo-referenced locations
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Sample unit centers must be geo-referenced in the field with GPS using latitude/longitude. Where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), the relevant location is the centroid of the primary unit. "Fuzzed" (uncorrected) locations of FIA plots recorded in the FIADB are used for the analysis.
Purpose of data	Matching
Comments	None

Data/Parameter	STDAGE
Data unit	Years
Description	Stand age
Equations	N/A
Source of data	Increment cores taken at breast height from sampled trees, obtained via plot-based sampling (see description of measurement methods for live aboveground biomass, *LAG*)
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	• Stand age calculated as average total age (age at breast height + the number of years that passed from germination until the tree reached the point of core extraction). • Stand age is estimated from increment cores from three or more representatively sampled live trees ≥5" dbh, and not over-topped, from within the project sample unit. • Core each tree at the point of diameter measurement and count the rings between the outside edge and the core to the pith. Add in the number of years that passed from germination until the tree reached the point of core extraction to determine the total age of the tree: 5 years for all eastern species, 5 years for western hardwoods, and 10 years for western softwoods. Compute the average age across all cored trees in the project sample unit.[45]

[45] Taken from USFS FIA Regional Field Guides for Standard (Phase 2) Measurements. Available at: https://www.fia.fs.usda.gov/library/field-guides-methods-proc/

Purpose of data	Matching
Comments	None

Data/Parameter	SITECLCD
Data unit	FIA Classes 1–7 (in cubic feet/acre/year) – see definitions in the FIADB User Guide
Description	Site productivity class code
Equations	N/A
Source of data	NRCS Web Soil Survey Database[46]
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	SITECLCD is determined for the sample unit location (center), or where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), SITECLCD is determined as the area-weighted average value for the primary unit. For each map unit, the relevant reference tree species in the NRCS Web Soil Survey is identified as the available tree species with the highest relative basal area, determined from plot-based sampling (see description of measurement methods for live aboveground biomass, *LAG*). Where a map unit has <NULL> site productivity values, SITECLCD is sourced from the map unit nearest to the project sample unit for which site productivity values are available.
Purpose of data	Matching
Comments	None

Data/Parameter	Regeneration stocking
Data unit	Dimensionless
Description	Total relative density per acre (Ducey and Knapp 2010) of all live trees ≥1” and <5” dbh of commercial species. Commercial species are defined as those not from species groups 23, 43, or 48 (see FIA Database User Guide Appendix E).
Equations	N/A

[46] Available at: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Source of data	Plot-based sampling (see description of measurement methods for live aboveground biomass, *LAG*)
Value applied	Between 0 and 1
Justification of choice of data or description of measurement methods and procedures applied	Relative density (RD) per acre is calculated for each individual tree as follows and is then summed for the sample unit: $RD_{per\ acre} = 2.47 \times \left((0.00015 + \left(0.00218 \times Specific\ Gravity_{Species}\right)\right) \times (\frac{dbh}{10})^{1.6}$
Purpose of data	Matching
Comments	None

Data/Parameter	Commercial stocking
Data unit	Dimensionless
Description	Total relative density per acre (Ducey and Knapp 2010) of live trees of commercial species, ≥5” dbh, with at least one sound, straight eight-foot section. Commercial species are defined as those not from species groups 23, 43, or 48 (see FIA Database User Guide Appendix E).
Equations	N/A
Source of data	Plot-based sampling (see description of measurement methods for live aboveground biomass, *LAG*)
Value applied	Between 0 and 1
Justification of choice of data or description of measurement methods and procedures applied	Relative density (RD) per acre is calculated for each individual tree as follows and then summed for the sample unit. $RD_{per\ acre} = 2.47 \times \left((0.00015 + \left(0.00218 \times Specific\ Gravity_{Species}\right)\right) \times (\frac{dbh}{10})^{1.6}$
Purpose of data	Matching
Comments	None

Data/Parameter	ELEV
Data unit	Feet (in 10- or 100-foot categories)
Description	Elevation

Equations	N/A
Source of data	GPS or digital elevation model
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	ELEV is determined for the sample unit location (center), or where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), ELEV is determined as the average value for the secondary units.
Purpose of data	Matching
Comments	As per Table A1.1, elevation may be considered optional.

Data/Parameter	SLOPE
Data unit	Percent
Description	Slope
Equations	N/A
Source of data	Digital elevation model or plot-based sampling with hypsometer or clinometer (sample unit average slope)
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Where determined referencing a digital elevation model, SLOPE is determined for the sample unit location, or where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), SLOPE is determined as the area-weighted average value for the primary unit.
Purpose of data	Matching
Comments	None

Data/Parameter	Quadratic mean diameter
Data unit	Inches (to the nearest 0.1 inch)
Description	Diameter of tree with average basal area
Equations	N/A

Source of data	Plot-based sampling (see description of measurement methods for live aboveground biomass, *LAG*)
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Based on live trees >5" dbh only
Purpose of data	Matching
Comments	None

Data/Parameter	RDDISTCD
Data unit	Code (0 to 9) – see definitions in the FIADB User Guide[47]
Description	Horizontal distance to improved road
Equations	N/A
Source of data	GIS analysis
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Calculated as the shortest straight line, overland distance from the sample unit center to the nearest improved road. An improved road is a road of any width that is maintained as evidenced by pavement, gravel, grading, ditching, and/or other improvements. Where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), the relevant location is the centroid of the primary unit.
Purpose of data	Matching
Comments	None

[47] Burrill, E. A., G. A., Christensen, B. L., Conkling, et al. 2023. *The Forest Inventory and Analysis Database: Database Description and User Guide Version 9.1 for Phase 2*. US Department of Agriculture, Forest Service. https://www.fia.fs.usda.gov/library/database-documentation/current/ver91/FIADB%20User%20Guide%20P2_9-1_final.pdf

APPENDIX 2: NFI ELEGIBILITY AND PERFORMANCE BENCHMARK PROCEDURES FOR PROJECTS OUTSIDE THE UNITED STATES

A2.1 Introduction

This Appendix enables the use of National Forest Inventories (NFIs) from countries other than the U.S., where such inventories meet defined methodological criteria. Applicable NFIs must be nationally coordinated forest monitoring programs that rely on statistically designed, systematically distributed, and periodically remeasured field plots to characterize forest extent, structure, growth, and management outcomes across large spatial scales. Because they are typically institutionalized, quality-controlled, and designed to support official reporting (e.g., national forest assessments and greenhouse gas inventories), applicable NFIs constitute a transparent and scientifically robust source of data suitable for constructing counterfactual baselines under VM0045.

Because NFIs vary substantially across countries in sampling design, plot density, temporal frequency, measured variables, and data accessibility it is necessary to ensure that only inventories providing sufficient rigor, representativeness, and comparability are used. This Appendix establishes a structured framework for evaluating whether a given NFI or complementary state-, tribal-, or other subnational inventory system will support the development of dynamic matched baselines consistent with the methodological requirements of VM0045.

Specifically, the framework must be used to evaluate:

- Statistical representativeness of the forest population, including coverage across forest types, ownership classes, and management regimes;
- Sampling and estimation design, including probability-based plot selection, remeasurement protocols, and documented estimation procedures;
- Temporal resolution and consistency, including the frequency and continuity of remeasurement cycles necessary to support dynamic baseline construction;
- Measurement protocols and data parameters, including alignment with biomass, growth, harvest, and carbon pool variables required under VM0045;
- Data transparency, documentation, and accessibility, ensuring that underlying data and methods are reproducible and subject to independent verification; and
- Methodological compatibility, including the ability to harmonize covariates and matching procedures with the dynamic baseline equations specified in *VM0045*.

Collectively, these criteria define the foundational requirements related to statistical representativeness, sampling and estimation design, temporal continuity, carbon-relevant measurement parameters, and data transparency, to ensure that inventories used to construct counterfactual donor pools provide unbiased, comparable, and temporally consistent information. By requiring statistical rigor, transparent documentation, and alignment with VM0045's matching framework, the Appendix safeguards the credibility of baseline estimates and ensures that dynamic baselines reflect like-for-like comparisons rather than artifacts of sampling design or data limitations.

In addition to these mandatory requirements, as outlined below, projects may incorporate additional variables, covariates, and/or harmonization procedures to strengthen ecological comparability between project and baseline plots. Such enhancements are intended to improve matching precision and reduce uncertainty; however, they do not substitute for the minimum eligibility criteria and do not alter the underlying accounting framework of VM0045.

A2.2 Assessment criteria for NFI quality

To be eligible for use under this methodology, any non-US NFI must meet the minimum dataset conditions defined in this section. The inventory must provide all variables required for matching, stratification and baseline construction. These criteria specify the minimum dataset, design, and documentation conditions required for eligibility. The detailed procedures for demonstrating compliance with these criteria are described below:

A2.2.1 ***Statistical Design and estimation framework:*** The NFI design must ensure that forest types, ecological zones, and ownership categories (e.g., private, public, communal, indigenous) that are materially represented within the population of interest are included within the sampling frame and are not systematically excluded from measurement. . The inventory must demonstrate that reported estimates are derived using design-consistent methods. Adequacy of sample size for constructing matched donor pools is assessed separately under the donor pool construction requirements:

a) **Sampling Approach:** The NFI must use a systematic, random, or other statistically valid probability-based sampling design implemented over a clearly defined and documented sampling frame. All units within the forest population must have known non-zero probabilities of selection.

b) **Plot Configuration and Remeasurement**: Plot design must be standardized, including plot locations that are either permanently established or part of a documented remeasurement system that enables consistent estimation of change over time. Any changes in plot configuration, measurement protocols, or definitions must be documented and demonstrably harmonized to maintain temporal consistency.

c) **Estimation and Variance Procedures:** Estimates of biomass and/or carbon stocks and stock changes (whether included in the NFI itself or implemented by the project using NFI measurements of biomass) must be derived using estimators appropriate to the sampling design. Expansion factors, stratification weights, and variance estimation methods must be transparently documented and statistically valid.

For clarity, estimators must correctly account for the probability-based sampling design of the NFI (e.g., simple random, systematic, stratified, or cluster sampling), such that estimates are unbiased or asymptotically unbiased with respect to the target population. Examples include, as applicable to the NFI design:

i) Area-weighted or expansion-factor estimators for simple random or systematic sampling (e.g., mean per plot × expansion factor);

ii) Stratified estimators using stratum-specific means and weights proportional to stratum area;

iii) Ratio or model-assisted estimators (e.g., generalized regression estimators) where auxiliary variables are used, provided that design consistency is maintained.

Proponents must demonstrate that the selected estimator is consistent with the documented NFI sampling design and follows established statistical practice. Estimation procedures that ignore the sampling design (e.g., simple unweighted averages where unequal selection probabilities apply) are not permitted.

A2.2.2 *Core Data Parameters*: The NFI must contain the variables necessary to quantify required pools as specified in Table A2.1 below and be derived via strict adherence to documented and transparent field measurement procedures. At a minimum, aboveground biomass (AGB), belowground biomass (BGB), and dead wood (DW) must be estimated using NFI data or equivalent plot-based datasets that meet the eligibility requirements in this section. Optional matching datasets may be used only to supplement, but not replace, these core estimates where they meet the applicable criteria (see Section A2.3 about Optional Matching Datasets – OMDs)..

A2.2.3 *Temporal Resolution* – The NFI must be based on a systematic and institutionalized remeasurement framework that supports estimation of carbon stock change over time:

a) **Remeasurement history**: each plot used for donor pool construction must have been measured at least twice under a consistent protocol to establish historical trends in carbon stocks. The remeasurement framework must enable estimation of stock change over defined time intervals not greater than 10 years and consistent with the dynamic baseline requirements outlined in Section 6 of this methodology.

b) **Temporal Relevance to Project Start:** in accordance with Section 6 (Baseline Scenario), initial conditions used to construct the baseline must be derived from measurements collected within the 10 years preceding the project start date (i.e., between $t_0 - 10$ and t_0, where t_0 is the project start date). The NFI remeasurement cycle must therefore provide at least one measurement within this temporal window to ensure that baseline conditions reflect recent forest dynamics. Where the most recent measurement cycle extends beyond this window, the NFI must demonstrate that updated stock change estimates are derived through its established, design-consistent estimation procedures.

Table A2.1. Description of parameters that all NFIs or optional matching datasets must collect to account for required and optional carbon pools as established in Section 5 (Project Boundary)

Carbon Pool	Included?	Minimum required NFI parameters	Notes
Aboveground tree biomass	Yes (Required)	• Tree species (scientific/common name) • Diameter at breast height (DBH) or diameter at specified height of measure (D-HOM) (such as defined distance above buttresses) • Total height and/or commercial height [48] • Unique tree identifiers for remeasurement are preferable but not mandatory	Design-consistent allometric equations or volume-to-biomass conversion factors appropriate to species or forest type as per Section 9.2 (Data and Parameters Monitored). Must enable estimation of live aboveground biomass stocks and stock change.
Aboveground non-tree woody biomass	Yes/Optional	• Species ID • Diameter and/or basal dimensions • Height or length (if measurable)	Must be included if project activities significantly reduce this pool and is also accounted in the baseline scenario.[49]
Belowground biomass	Yes (Required)	• Derived from aboveground DBH/height/species data using component ratio methods (root-to-shoot ratios, IPCC/locally derived)	Direct destructive sampling is not required; ratios must be documented. See Table 9.2 for detailed procedures.
Dead wood (standing and lying)	Yes (standing DW is required)	• DBH and total height for standing dead trees, including decay class • Diameter/length/decay class for coarse lying deadwood	Lying dead wood may be included only where it is possible to account for it in both the project and baseline scenarios.[50]
Litter	Yes/Optional	• Litter layer thickness (duff + litter) • Bulk density or equivalent measure (if NFI protocol allows)	Required only if project activities significantly reduce this pool, and if pool is accounted in the baseline scenario.

[48] If tree biomass is estimated using height, measurements must be sufficient to support unbiased, precise biomass estimates using an h–d (height–diameter) model. If a h-d model is used, it is expected that relative height prediction error is ≤10% and shows no bias by DBH). Tree total (or commercial) height is usually measured in a sub-sample plot within the core plot. For example, in tropical forests, a conservative threshold of sampling ~50 trees per location for height measurement and including the ten trees with the largest diameter in this sample is recommended (Sullivan et al. 2019). See section 9.2 of data parameters monitored.

[49] Non-tree aboveground woody biomass pool includes trees smaller than the minimum tree size measured in the tree biomass pool, all multi-stemmed shrubs, and all other non-herbaceous live vegetation. Non-tree vegetation biomass can be derived from peer-reviewed literature and must be appropriate to the species in the project area or to the geographic region, elevation and precipitation regime in the project area. It can also be sampled using destructive sampling frames and/or, where suitable, in sampling plots in combination with an appropriate allometric equation.

[50] As shown in section 9.2, biomass of standing and lying dead wood must be estimated from sampled volumes using published wood densities specific to species, genus, or family, in descending order of preference, as available and density reduction factors referencing decomposition states.

Soil organic carbon	Yes/Optional	• Soil depth (to at least 30 cm, deeper if there is a significant disturbance) • Bulk density • Carbon concentration	Must be included where the project activity significantly reduces the carbon pool. Project proponents may choose to include this source where the change is deemed insignificant, and if pool is accounted in the baseline scenario.

Note — As shown in section A2.3 below, aboveground biomass (AGB), belowground biomass (BGB), and dead wood (DW) must be estimated using NFI data or equivalent plot-based datasets that meet the eligibility requirements. For other required or optional carbon pools not directly measured within the NFI, optional matching datasets may be used to supply the specific parameter necessary to enable estimation of that pool within the NFI's design-consistent framework. Such data must not replace the underlying probability-based sampling design, must not serve as an independent source of stock-change estimation, and must not constitute an alternative monitoring system. All carbon stock and stock-change estimates must remain grounded in the NFI's documented inference structure.[51]

A2.2.4 ***Official Management and Access***: An NFI must be implemented and managed by an official national or subnational authority, or by an entity formally mandated by such type of authority. Project proponents must demonstrate that the NFI dataset, including plot-level data and associated metadata, is publicly available or that a clear and verifiable pathway to access plot-level data, metadata, and methodological documentation exists, enabling independent verification of representativeness by project proponents and validation/verification bodies.

A2.3 Optional Matching Datasets

Optional Matching Datasets (OMDs) are supplementary datasets that may be used alongside an eligible National Forest Inventory (NFI) to enhance the construction of matched donor pools under VM0045. OMDs are not required for eligibility and must not substitute for deficiencies in the NFI or its sampling design. OMDs may contribute plots to the donor pool, provided that their inclusion is demonstrably consistent with the methodological requirements of this Appendix and does not compromise the representativeness of business-as-usual (BAU) conditions. In all cases, the NFI must remain the primary basis for design-consistent inference and baseline estimation.

Where an NFI independently satisfies all assessment criteria for NFI quality (Section A2.2) but exhibits limitations for donor-pool construction (e.g., low plot density within relevant ecological domains, incomplete representation of ownership or management conditions, or insufficient coverage within specific forest types), project proponents may incorporate additional statistically

[51] Inference structure refers to the statistical framework defined by the NFI's sampling design and estimation procedures, including the probability-based selection of plots, associated expansion factors or weights, stratification (if applicable), and the design-consistent estimators used to derive population-level carbon stock and stock-change estimates. This ensures that all estimates are traceable to the NFI's established, unbiased inference approach and are not derived independently from auxiliary or model-based data sources.

compatible datasets. These may include state-, tribal-, or other subnational inventory systems, as well as eligible supplementary datasets ("Optional Matching Datasets", OMDs), to strengthen donor-pool representativeness and improve ecological comparability between project and baseline plots. Accordingly, OMDs may serve two distinct functions:

1) ***Donor Pool Augmentation***: Where the eligible NFI dataset provides limited representation within specific ecological zones, ownership classes, or management conditions relevant to the project area, additional statistically compatible datasets may be incorporated to augment the donor pool. Thus, OMDs must:
    - be probability-based or otherwise demonstrably representative of business-as-usual (BAU) conditions within the relevant jurisdiction;
    - be harmonized with the NFI to ensure consistency in definitions, measurement protocols, and temporal scope.
    - augment, but not replace, the NFI sampling framework, and their inclusion must not introduce systematic bias or disproportionately influence the donor pool relative to the NFI dataset.
2) ***Matching Refinement and Covariate Enhancement***: Project proponents may incorporate transparently documented, statistically valid OMDs —such as small area estimation outputs or remote-sensing-derived covariates—to refine stratification, improve covariate alignment, or enhance assessments of environmental similarity. These datasets must be used in a model-assisted, but not model-based, manner. Further, they must not be used to generate pseudo-plots, independently estimate biomass, or serve as alternative baseline data sources.

Optional matching datasets may include additional variables, remote sensing layers, sub-national inventory datasets, or other plot-based data sources, provided they:

- Are independent from the project proponent and not derived from project-specific data;
- Are validated, transparently documented, and harmonized with the NFI in terms of definitions, measurement protocols, and temporal scope;
- Are publicly accessible or fully auditable;
- Are statistically compatible with the underlying NFI population. That is, these datasets must augment, not replace or reweight, the original NFI sampling frame;
- Are used in a manner consistent with the matching framework of this methodology; and
- Do not alter the population definition, sampling structure, or inference basis of the core NFI. This means that these datasets must not introduce modeled biomass estimates, pseudo-plots, or independently derived stock-change estimates;

During validation, project proponents must demonstrate full compliance with all minimum NFI eligibility requirements defined in this Appendix. The use of optional matching datasets does not confer preferential treatment in crediting, uncertainty deductions, or conservativeness factors. Any reduction in uncertainty deductions must arise exclusively from empirically demonstrated reductions in statistical uncertainty, as quantified through the methodology's equations (e.g., Section 8), irrespective of whether enhancement data are used.

Once an NFI (together with any optional enhancement data, where applicable) is determined to meet the minimum eligibility requirements of this Appendix, the project must apply the existing equations for additionality and crediting baseline—specifically, Equation (1) for demonstrating additionality and Equation (6) for deriving the crediting baseline—using the matched donor pools and weights defined herein. The criteria below ensure that selected optional datasets are compatible with the methodology's requirements for constructing dynamic baselines and quantifying changes in carbon stocks between baseline and project scenarios.

A2.3.1 *NFI data augmentation using optional matching datasets*: Each dataset must demonstrate:

a) **Measurement compatibility:** Variables in the optional matching datasets must allow the estimation of required parameters using methods aligned with the project's measurement protocols (e.g., minimum DBH). Where an NFI has been deemed suitable as per section A2.2 above, but is incomplete or limited, optional matching datasets from the same jurisdiction as the project or a different one (within the same country as the project) may be used if:

   - comparability is demonstrated on ecological, silvicultural, and socio-economic dimensions through covariate balance and a documented narrative on management context, policy environment, tenure mix, species/forest type composition, and accessibility. Where applicable, demonstration that the conditions represented (e.g., plantation management regimes) are consistent with business-as-usual practices in the region is required;
   - robustness checks (e.g., transportability tests, placebo analyses, or sensitivity analyses) show that baseline inferences remain consistent when jurisdictions are excluded or alternative covariate sets are used[52];
   - when definitions or protocols differ (e.g., forest definitions, height thresholds, land-use classes), proponents implement bridging functions[53] and harmonization procedures consistent with best practices and document any residual differences.

b) **Design integrity:** Datasets must originate from a documented probability sample (e.g., systematic, random, or stratified), with clearly defined plot/cluster designs, remeasurement intervals, and QA/QC procedures. Optional matching datasets must be independent from the project proponent and not derived from project-specific data, and must have a clearly documented and verifiable source, including datasets maintained by government agencies, or third-party organizations, as well as privately managed plot networks, provided that data provenance, sampling design, and measurement protocols are transparently documented and subject to validation.

[52] E.g., leave-one-jurisdiction-out tests, alternative covariate specifications, or placebo checks in areas with no expected treatment effect.

[53] A documented, reproducible mapping function/protocol that accurately transforms measurements, definitions, and classification rules from a non-conforming plot dataset into the variables and units required by VM0045 (e.g., DBH thresholds, live/dead classes, volume/biomass equations, forest definition, expansion factors). The function must (i) place estimates on the same scale, (ii) quantify and carry its own added uncertainty, and (iii) pass balance/bias checks so the augmented dataset is statistically comparable for baseline construction; otherwise, the source dataset is ineligible. See more in McRoberts et al. (2009).

c) **Ecological and temporal alignment:** Plots must first be drawn from the same ecoregion or life zone. Expansion beyond the focal ecological domain must follow the donor-pool hierarchy (see Table A2.3), and must be justified through documented covariate balance and environmental similarity assessments.

d) **Temporal consistency:** Optional datasets must be temporally aligned with the baseline period used under Section 6. Measurement years for supplemental datasets must fall within ± 5 years of the measurement window used to define initial conditions (i.e., t − 10 or more recently) and must adhere to the following principles:

- Where measurement periods fall outside this tolerance, proponents must demonstrate that forest conditions, management regimes, disturbance patterns, and policy environments are sufficiently stable such that inclusion of the dataset does not materially bias donor-pool selection. Such justification must include documented sensitivity analyses or exclusion tests showing that baseline inferences remain consistent when temporally divergent plots are omitted.
- Temporal alignment requirements under this section apply solely to donor-pool construction and matching. They do not modify the requirement under Section 6 that initial conditions be quantified from measurements collected at time t − 10 or more recently.

e) **Documentation and access:** Datasets must be publicly available or accessible under reasonable terms, with complete metadata describing sampling design, variables, QA/QC protocols, field manuals, crew training, instrument calibration, and error-checking procedures.

f) **Performance and validation of model-assisted data:** Where optional datasets are derived from model-assisted approaches (e.g., small area estimation outputs, geostatistical interpolation of environmental variables, or remote-sensing–based covariates), proponents must document data sources, model structure, and processing steps, provide independent validation demonstrating fitness for stratification, covariate alignment, or environmental-similarity assessments, ensure temporal consistency with the baseline period and demonstrate that any bias or uncertainty does not materially affect donor-pool selection or matching.

g) **Sensitivity Analysis:** Where OMDs contribute materially to the donor pool, the Project Proponent must provide a sensitivity analysis comparing baseline estimates derived using NFI-only donor pools, and baseline estimates derived using NFI + OMDs donor pools. Any material differences must be explained and justified.

A2.3.2 *Integration and Alignment of optional matching datasets*: Optional matching datasets must conform with international standards (e.g., IPCC Good Practice Guidance, UNFCCC, CBD, FAO FRA) and demonstrate explicit design features that enable harmonization with remote sensing and auxiliary data sources.

This methodology does not establish universal numerical performance thresholds (e.g., specific R^2 or RMSE values). Proponents must justify that dataset performance is adequate for the forest context and fit for its intended role in donor-pool construction or matching refinement.

To illustrate how core NFI data and optional matching enhancements function within VM0045, the example below (Box 1) presents a step-by-step process by which subnational inventory plots may augment—without replacing—the eligible NFI foundation. The example demonstrates how optional datasets can be harmonized, evaluated for comparability, and combined into a composite donor pool consistent with the matching framework. The illustration is intended to clarify permissible procedures and does not modify eligibility requirements, baseline accounting rules, or uncertainty provisions of the methodology.

Box 1. Example: Integration of Core NFI Data and Optional Matching Datasets

Context: *A project is located in the upper montane zone of Ecoregion A. The national NFI satisfies all Core Eligibility Requirements under this Appendix but has relatively low plot density at high elevations and limited recent remeasurements in the specific forest type relevant to the project.*

To improve ecological comparability and donor-pool robustness, the proponent incorporates:

1. Supplemental field-based plots from a neighboring jurisdiction within the same ecoregion;
2. Remote sensing structural metrics (e.g., canopy height model from airborne LiDAR or GEDI footprints), used solely as matching covariates;
3. Small Area Estimation (SAE) methods to improve precision within rare strata.

Note — All optional datasets comply with Optional Matching Enhancement requirements and do not replace the design-based NFI foundation.

Step 1 — Establish the NFI Foundation
The NFI meets all Core Eligibility Requirements:

- Probability-based national sampling design
- Compatible DBH thresholds and measured variables
- Documented remeasurement cycles consistent with Section 6
- Transparent QA/QC and accessible metadata

Note — Within the relevant upper montane mixed-forest domain, however, only 14 NFI plots are available. The NFI remains the foundational dataset.

Step 2 — Add Supplemental Field-Based Plots
The proponent identifies 54 inventory plots from a neighboring jurisdiction within the same ecoregion and management context. The following differences are identified:

- DBH minimum differs (NFI 10 cm; supplemental plots 12 cm)

- Height measurement protocols differ (clinometer vs. hypsometer)

Prior to integration, the project proponent:

- Restricts both inventories to the higher minimum dbh (no taper modeling)
- Demonstrates ecological and management comparability
- Conducts sensitivity checks excluding the supplemental dataset

Note — No pseudo-plots are created, and no modeled biomass estimates are introduced.

Step 3 - Assess Influence of OMDs on Donor Pool Composition

The project proponent provides a quantitative description of the role of OMDs in the donor pool, including: a) Number and proportion of donor plots derived from OMDs relative to the NFI; b) Distribution of OMD plots across key covariates (e.g., forest type, management class, ecological zone). Where OMDs represent a substantial share of the donor pool, additional justification must be provided to demonstrate that their inclusion does not bias baseline outcomes.

Step 4 — Incorporate Remote Sensing as Matching Covariates

Remotely sensed estimates of canopy height and canopy cover metrics (e.g., from LiDAR or GEDI) are incorporated as additional covariates in the matching algorithm. These covariates allow:

- More precise stratification of donor and project plots
- Identification and exclusion of ecologically dissimilar plots
- Improved alignment in structural attributes (e.g., height-age relationships)

Remote Sensing data must:

- Be temporally consistent with the baseline period
- Be spatially co-registered with plot locations
- Be independently validated (e.g., reporting RMSE and bias)
- Be used only for stratification and matching refinement

Remote sensing outputs must not be used to:

- Estimate biomass stocks
- Replace field plot measurements
- Generate pseudo-plots
- Modify VM0045 accounting equations

Note — By expanding the covariate space used for matching, the proponent may alter donor pool composition (e.g., through refined weighting or exclusion of outliers), thereby improving covariate balance between project and matched control plots.

Step 5 — Apply Small Area Estimation (SAE) for Domain Precision

The high-elevation stratum is rare and sparsely sampled (14 NFI + 54 supplemental plots). To improve precision at the domain level, the proponent applies an area-level (e.g., Fay–Herriot) or unit-level SAE model.

SAE outputs are used only to:

- Refine domain-level means
- Improve stratification
- Support covariate-aligned comparability

SAE is not used to:

- Predict plot-level biomass
- Replace design-based estimators
- Generate carbon stock estimates

Step 6 — Construct the Composite Donor Pool

The donor pool consists of:

- 14 eligible NFI plots
- 54 harmonized supplemental plots
- Remote sensing covariates used for matching balance
- SAE-refined domain means used for stratification support

A2.4 NFI Eligibility Assessment

To operationalize the criteria in Sections A2.2 and A2.3 above, eligibility of an NFI or optional dataset under this Appendix must be determined at the inventory-design level (i.e., based on the dataset's sampling design, measurement protocols, and estimation framework, rather than its application in a specific project), and recorded by Verra. Subsequent projects may rely on this determination where the same dataset source and version are used, and where all applicable requirements of this Appendix continue to be met. Eligibility recognition at the NFI level does not exempt individual projects from demonstrating compliance with project-specific requirements, including temporal alignment with Section 6 (Baseline Scenario), donor-pool construction criteria, and matching procedures. Where substantive modifications to the NFI design or estimation framework occur, reassessment may be required.

A2.4.1 *First-Time NFI Eligibility Assessment*

Where an NFI has not previously been assessed, the project proponent must submit the required documentation to Verra to initiate an eligibility review prior to or in parallel with project validation.

An official attestation must be provided by the national authority or lead institution responsible for the NFI (or their designated scientific representative) confirming that:

(i) the documented sampling design, measurement protocols, and estimation procedures are accurate and reflect the official NFI methodology;

(ii) the documentation provided is complete to the best of their knowledge; and

(iii) any known limitations relevant to interpretation of the dataset are disclosed.

Where such attestation cannot be reasonably obtained, the project proponent may submit alternative documentation demonstrating the authenticity, completeness, and official status of the NFI, subject to review and validation by VVBs. Such documentation must, at a minimum, identify whether the NFI meets the eligibility requirements of this Appendix for use under this methodology. This determination applies at the dataset level and may be relied upon by subsequent projects using the same dataset.

A2.4.2 *Use of an Already-Approved NFI*

- Where an NFI has been previously assessed and deemed eligible by Verra under this Appendix, the Project Proponent may rely on that prior eligibility determination without repeating the full assessment, provided that all requirements below are satisfied. The Project Proponent must:

  (i) Demonstrate that all core dataset elements used for baseline construction were obtained directly from the approved NFI or its official data repository;

  (ii) Provide evidence of data provenance (e.g., official download records, dataset identifiers, or institutional transmittal letters) confirming that all core NFI data originate from the official source; and

  (iii) Document any project-specific harmonization, filtering, stratification, or matching procedures applied to the dataset, ensuring that such steps do not modify the underlying inference structure of the NFI.

  (iv) Demonstrate that the NFI dataset used corresponds to the same inventory system, sampling design, and estimation framework as the version previously approved; and

  (v) Demonstrate that any updates to the NFI (e.g., additional measurement cycles, revisions to estimation procedures, or changes in sampling design) are documented and do not materially alter the basis on which eligibility was originally determined.

- The Validation/Verification Body (VVB) must confirm during validation that:

  (i) the NFI applied is consistent with the version previously approved by Verra; and

  (ii) all project-specific data preparation steps are applied in accordance with the requirements of this Appendix.

Verra maintains a record of NFIs for which eligibility under this Appendix has been recognized. Where a project proposes to use an NFI that has previously been recognized as eligible, validation may rely on prior eligibility determination, subject to the conditions above.

Verra may require a renewed eligibility assessment where material changes to the NFI design, estimation procedures, or data content are identified that could affect the validity of the dynamic baseline construction. Thus, the project proponent must confirm that the NFI dataset used remains consistent with the version and design previously deemed eligible and must disclose any known changes that could affect compliance with the requirements of this Appendix.

Recognition of NFI eligibility does not exempt the project from demonstrating compliance with donor-pool construction, temporal alignment (Section 6), or matching procedures specific to the project context.

A2.5 Documenting eligibility for NFIs and OMDs

The following rules must apply to the assessment and documentation for eligibility of NFIs and optional matching datasets. These provisions ensure consistency, maintain methodological integrity, and provide sufficient evidence for validation and verification.

(a) Mandatory Core NFI Eligibility Requirements

- **Documented Evidence Requirement:** Project proponents must provide official documentation or formal written confirmation from the institution responsible demonstrating compliance with each assessment criteria for NFI quality. Assertions without supporting evidence are not considered valid.
- **Mandatory Compliance:** All assessment criteria for NFI quality must be satisfied as a condition of NFI eligibility under this methodology. Failure to meet any criteria renders the NFI ineligible.
- **Resolution of Ambiguity:** Where ambiguity exists in documentation or interpretation, clarification must be sought from the responsible NFI authority. Where material uncertainty remains that could affect representativeness, statistical validity, or unbiased baseline construction, conservative assumptions must be applied in baseline development or uncertainty estimation.

(b) Optional Matching Datasets

- **Consistency with Assessment criteria for NFI quality:** Optional Matching Enhancements may be applied to augment the donor pool, improve covariate resolution, representativeness, or matching precision, provided they do not compromise compliance with the Assessment criteria for NFI quality.
- **Transparency and Documentation:** Any enhancement applied must be fully documented, including harmonization procedures, dataset characteristics, and statistical justification, and must be made available to the VVB for independent review.
- **No Substitution of Core Requirements:** Optional Matching Enhancements must not be used to compensate for failure to meet any Assessment criteria for NFI quality.

(c) Procedural Safeguards

- **Transparency of Assessment:** The full eligibility assessment, justification under each requirement, and all supporting documentation must be included in the project description.
- **Official Institutional Attestation:** Projects conducting an NFI Eligibility Assessment for the first time must meet the requirements outlined in section A2.4.1 above. This attestation does not replace independent technical validation.

A2.6 Performance benchmark method

The performance benchmark is a central element of this methodology to ensure that baseline scenarios reflect the observed performance of comparable forests under similar ecological and management conditions. The procedures explained below are designed to ensure functional equivalence with Appendix 1 in terms of statistical representativeness, unbiased sampling, and like-for-like matching logic, while preserving the accounting framework and equations specified in the body of the methodology.

A2.6.1 Baseline Scenario

The baseline scenario must be established using a performance benchmark constructed from eligible National Forest Inventories (NFIs) or other approved state-, tribal-, or subnational inventory systems, and optional matching datasets that satisfy the requirements outlined in Sections A2.2 (Assessment criteria for NFI quality) and A2.3 (Optional Matching datasets) of this Appendix. Project proponents must establish the baseline as follows:

1) **Donor Pool Definition**: Identify all eligible NFI plots, and any datasets qualifying under Optional Matching Datasets, that correspond to forest conditions comparable to those of the project area, including forest type, ecological zone, ownership or tenure class, and management context. This step establishes the candidate donor pool from which matched baseline plots will be selected. Optional datasets must not substitute for failure to meet Assessment criteria for NFI quality (Section A2.2)..All dataset provenance, harmonization procedures, and inclusion criteria must be fully documented.

2) **Estimation of Baseline Stock Change (Benchmark Construction)**: For each project stratum, match project sample units to statistically comparable donor plots using the covariates specified in this Appendix. Using the matched donor plots, calculate observed annual carbon stock change between at least two successive measurement cycles. The most recent cycle must be sufficiently recent to reflect contemporary forest dynamics; where older than ten years prior to project start, justification must be provided demonstrating continued representativeness.

The stratum-level benchmark must be calculated as the pre-specified k-nearest-neighbor weighted mean of observed stock-change values across matched donor plots. The choice of k, distance metric, and weighting scheme must be justified and subject to sensitivity analysis.

3) **Application to the Project Area**: The benchmark derived in Step 2 below constitutes the dynamic baseline for the corresponding project stratum. Project proponents must document all matching procedures, harmonization functions, weighting rules, donor pool characteristics, and robustness checks applied in generating the benchmark.

A2.6.2 Performance Benchmark

In the international context of this Appendix, the performance benchmark is defined as the observed rate of carbon stock change under prevailing management conditions for forests statistically comparable to the project area. The benchmark is estimated from donor pools composed of eligible

NFI plots or other approved plot-based datasets that satisfy the Assessment criteria for NFI quality and, where applied, the Optional Matching Datasets Requirements.

Matching is performed to ensure that donor pools reflect key ecological, structural, and management characteristics of the project area. Weights are assigned using a pre-specified distance metric and weighting rule to reflect the relative similarity between project sample units and donor plots. The benchmark informs two key components of the methodology:

- **Additionality test**: The benchmark provides the empirical counterfactual against which project management practices are evaluated to demonstrate departure from observed prevailing performance (Equations 1-2).
- **Crediting baseline**: The benchmark defines the expected trajectory of carbon stock change in the absence of the project, providing the reference against which project impacts are quantified (Equations 6-8).

Both applications rely exclusively on repeated measurements of the underlying NFI or other eligible plots, ensuring that benchmark values are derived from observed stock-change between successive measurement cycles rather than modelled baseline assumptions. Matching procedures, weighting methods, and robustness checks are detailed in the following section.

A2.6.3 Composite Baseline Procedures for projects outside the United States

The composite baseline must be developed using matched donor pools derived from eligible NFIs or other approved plot-based datasets in accordance with the following steps:

Step 1. Define Project Sample Units (PSUs)

Project Sample Units (PSUs) are the smallest analytical units within the project area used to establish matched comparisons with donor-pool plots. PSUs represent the full set of forested units within the project boundary for which composite baselines must be constructed. PSUs may correspond to a) Individual project monitoring plots; or b) Homogeneous analytical units defined by ecological, structural, or management characteristics.

a) **Alignment with Project Stratification:**

   i) PSUs must correspond to the project's monitoring units or other discrete measurement units used to quantify stock change. Pre-stratification is not required.

   ii) Where appropriate, PSUs must be grouped into homogeneous strata after matching, based on observed stock-change behavior or ecological similarity. Such grouping must not alter the original matching process.

   iii) PSUs must collectively represent all forested areas within the project boundary for which dynamic baselines are required.

b) **Minimum Covariate Information:**

Each Project Sample Unit (PSU) must be characterized using the covariates required for donor-pool matching as specified in Table A2.2 below. The table identifies the covariates used in the matching algorithm, their classification (e.g., exact-match, core continuous, or optional), and their role in the nearest-neighbor distance metric. Required covariates must be included for all PSUs and donor plots unless they are demonstrated to be non-informative due to negligible variation across the relevant matching domain or unavailable in a consistent and comparable form. Optional covariates may be included where reliable and consistently defined data are available and where their inclusion improves matching precision without materially reducing overlap. To limit dimensionality in the nearest-neighbor algorithm, the total number of covariates included in the distance metric should generally not exceed eight, including both core and optional covariates.

c) **Spatial Delineation:**

PSUs must be georeferenced and mapped, ensuring consistency with project boundaries and monitoring documentation. PSU size is not prescriptive; however, each PSU must represent conditions that can be reliably matched to donor-pool plots using the required covariates.

d) **Temporal Consistency:**

PSU covariates used for donor-pool matching must be defined at the project start date and remain fixed for purposes of baseline construction. If stand conditions change materially after project starts (e.g., due to harvesting, disturbance, or regeneration), project proponents must document such changes for monitoring purposes. Subsequent re-stratification for monitoring does not alter the original baseline matching process.

Step 2. Construct Donor Pools

Donor pools provide reference observations from outside the project area that reflect observed forest dynamics under prevailing management conditions. For each PSU, a donor pool must be established from eligible NFI plots or other approved plot-based datasets that satisfy the Assessment criteria for NFI quality and represent statistically comparable forest conditions. Donor pools must be constructed as follows:

a) Identify Eligible Datasets:

i) Donor plots must be drawn from datasets that meet all Assessment criteria for NFI quality, including representative sample design, statistical validity, temporal resolution, required data parameters, and institutional governance. Following application of the donor pool definition filters (e.g., forest type, ecological zone, tenure class, management context), the resulting donor pool must contain a sufficient number of plots to support robust statistical matching and estimation of baseline carbon stock change. Where filtering results in a very limited number of candidate plots, proponents must justify that the donor pool remains adequate to support reliable matching (see the example in Box 1 above).

ii) Where NFI coverage does not provide sufficient matched plots for a given PSU (see Minimum Plot Requirements below), supplementary datasets qualifying under Optional Matching datasets (section A2.3) may be integrated, provided that harmonization procedures and bridging functions are transparently documented and statistically justified.

iii) Optional Matching datasets must not substitute for failure to meet Assessment criteria for NFI quality indicated in Section A2.2.

b) Minimum Plot Requirements:

i) Donor plots must include at least one complete measurement cycle (i.e., two successive measurements) sufficient to estimate observed stock changes.

ii) The most recent measurement cycle must be sufficiently recent to reflect contemporary forest dynamics. Where the most recent measurement is older than ten years prior to the project start date, justification must be provided demonstrating continued representativeness.

iii) Plot designs must allow consistent measurement of required carbon pools (see Table A2.1 above) across successive measurement cycles.

iv) Attestation from the entity responsible for providing the data, or alternative verifiable evidence (e.g., statutory mandate, institutional program documentation), providing reasonable assurance (i.e., to the best of one's knowledge) that the inventory is part of an ongoing measurement program with periodic remeasurement, and that the dataset is expected to remain available for the duration of the project's crediting period.

b) Donor Pool Adequacy

i) For each PSU, the donor pool must be of sufficient size and diversity to produce a statistically stable benchmark estimate. Project proponents must demonstrate that benchmark results are not unduly sensitive to individual donor plots, including through appropriate robustness or sensitivity analyses of matching parameters and weighting schemes.

ii) Where donor pools are highly constrained due to rare forest types, tenure classes, or geographic isolation, proponents must document the limitation and apply conservative assumptions where necessary.

c) Coverage and Representativeness

i) Donor plots must be selected first from the same forest type and same ecoregion or life zone as the PSU.

ii) Where the donor pool is insufficient, stepwise expansion may occur into ecologically adjacent or closely related units, but *only* where ecological similarity can be demonstrated using required matching covariates and, where appropriate, optional matching datasets such as topographic, climatic, or remote-sensing–derived ecological indicators (e.g., canopy cover, vegetation indices).

iii) Expansion into ecologically dissimilar forest types or ecoregions is not permitted, regardless of statistical covariate matching.

d) Harmonization Across Datasets

i) Where donor plots come from multiple sources or jurisdictions, project proponents must document harmonization procedures for definitions (e.g., forest definition, DBH thresholds, tenure classes) and apply bridging functions as needed.

ii) Residual differences must be described and justified in the project description.

e) Transparency and Documentation

i) The full set of donor plots used in the analysis, including associated metadata (e.g., location—where necessary, geo-obfuscated or fuzzed—sampling design, measurement dates, variables collected, and QA/QC procedures), must be documented in a manner sufficient to enable independent validation and verification by the VVB.

ii) Where access to detailed plot-level or tree-level data is restricted due to confidentiality, legal, or institutional constraints, the Project Proponent must demonstrate that:

- The data have been obtained from an official or authorized source;
- Sufficient access has been granted to the VVB to independently assess the construction of the donor pool, matching procedures, and resulting estimates (e.g., through secure data access, controlled environments, or third-party verification); and
- The absence of publicly available raw data does not prevent replication or verification of results to a level consistent with the requirements of this methodology. In such cases, aggregated or derived datasets may be used only where they retain the necessary resolution to support plot-level matching and donor pool construction under VM0045. Summary statistics alone (e.g., stratum-level averages) must not be considered sufficient.

iii) Any exclusions (e.g., plots with incomplete data, disturbed plots outside project comparability criteria) must be clearly reported.

Step 3. Matching Procedure

Matching aligns each Project Sample Units (PSUs) with statistically comparable donor plots so that baseline estimates reflect observed forest performance under prevailing ecological and management conditions. Each PSU is linked to a donor pool through a transparent and reproducible matching process based on standardized covariates. The weighted donor pool defines the expected counterfactual performance benchmark for that PSU:

a) **Covariate Framework:**

i) Matching must be conducted using a standardized set of covariates capturing the primary drivers of forest growth, structure, and management context, as specified in Table A2.2 below.

ii) Optional covariates may be incorporated to improve matching precision, provided they are consistently defined across both PSU and donor datasets and where their inclusion improves matching precision.

iii) Covariates must be standardized and scaled prior to matching to ensure comparability across measurement units and to prevent undue influence of variables with larger numerical ranges.

b) **Matching Method:**

Matching applies a *k*-nearest neighbor optimal matching approach with replacement, with *k* equal to 10. For each donor plot in the eligible pool, initial condition covariates must be calculated from the most recent plot measurements collected prior to the project start date. Mahalanobis distances must then be calculated relative to each Project Sample Unit (PSU). For each PSU, the 10 donor plots with the lowest Mahalanobis distances must be selected, and relative weights must be derived proportional to the inverse of the Mahalanobis distance, normalized to sum to 1, as shown in Equation A2.1

$$W_{bsl,i,j} = \frac{{}^{1}/_{MD_{ij}} \times 100}{\sum_{j=1}^{10} {}^{1}/_{MD_{ij}} \times 100} \quad \text{(A2.1)}$$

Where:

$W_{bsl,i,j}$	=	Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1 (dimensionless)
MD_{ij}	=	Mahalanobis distance of constituent baseline plot *ij* relative to project sample unit *i* (dimensionless)

c) **Match quality:**

To ensure that donor pools provide valid counterfactuals for Project Sample Units (PSUs), project proponents must demonstrate that the covariate balance after matching meets minimum quality standards. Weighting must reflect the relative similarity between PSU and donor plots based on covariate distance. The procedure must be reproducible and documented in sufficient detail to allow independent replication by the VVB. For each covariate included in the matching vector, standardized mean differences (SMDs) between PSUs and matched donor pools must be calculated using equation A2.2 below:

$$SDM = \left|\overline{x}_{wp,x} - \overline{x}_{bsl,x}\right| \Big/ \sqrt{\left(\frac{\sigma^2_{wp,x} + \sigma^2_{bsl,x}}{2}\right)} \quad \text{(A2.2)}$$

Where:

SDM	=	Standardized difference of means
$\overline{x}_{wp,x}$	=	Mean value of covariate x in the population of sample units representing the project scenario
$\overline{x}_{bsl,x}$	=	Mean value of weighted sum of covariate x in the population of matched composite baselines representing the baseline scenario
$\sigma^2_{wp,x}$	=	Sample variance of covariate x in the population of sample units representing the project scenario
$\sigma^2_{bsl,x}$	=	Sample variance of covariate x in the population of sample units representing the baseline scenario

Table A2.2 below consolidates the minimum raw variables required within an eligible National Forest Inventory (NFI) or other approved plot-based datasets, along with the derived covariates used for donor-pool matching. Each covariate is classified according to its role in the matching algorithm as:

- E – Required Exact Match
- CC – Core Required Continuous
- OC – Optional Continuous
- OE – Optional Exact

Core continuous covariates must normally be included in the distance metric. However, a core covariate may be omitted where it is demonstrated to be non-informative due to negligible variation across the relevant PSUs and donor pool or where it is unavailable in a consistent and comparable form. To maintain statistical performance and limit dimensionality in the nearest-neighbor algorithm, the total number of covariates included in the distance metric should generally be limited to no more than eight, including both core and optional covariates. Any deviation from this range shall be justified and supported by diagnostic testing demonstrating maintained or improved match quality.

Overall match quality must be evaluated using the standardized mean difference (SMD) for each required covariate. A match is deemed acceptable where the absolute SMD for each required covariate is ≤ 0.25.

Where acceptable balance is not achieved under the default matching parameters, proponents must evaluate a predefined sequence of alternative nearest-neighbor configurations using k values of 10, 7, 5, and 3. If balance remains infeasible, proponents may apply only the adjustments shown in Table A2.3 below.

Project proponents must apply the Match Quality Decision Ladder (Table A2.3) to ensure that donor pool matching meets the minimum balance criterion of absolute standardized mean difference (SMD) ≤ 0.25 for all required covariates.

Where balance is not achieved under the default configuration ($k = 10$), proponents must evaluate the predefined sequence of alternative k values specified in Table A2.3 below and report balance statistics for each configuration. If balance remains infeasible, proponents may remove optional (non-required) covariates that materially restrict overlap, while required covariates remain fixed.

If balance cannot be achieved after applying the permitted adjustments, proponents must redefine PSUs (e.g., through aggregation) or conclude that a statistically valid composite baseline cannot be constructed for the affected PSU under this Appendix.

Table A2.2. List of covariates for obtaining matches of composite baselines from NFIs and other acceptable plot-based networks (see also Data and parameters available at validation for project sample unit below).

Covariate Dimension	Parameter / Data	Symbol	Unit	Description	Match Role	Requirement	Notes/Sources
Spatial location	Distance to project/sample unit	Dist	km	Geographic distance between donor plot and project sample unit Distance	Distance	CC	Derived from plot coordinates where available. May be omitted where NFI coordinate confidentiality prevents reliable calculation.
	Latitude	Lat	Decimal degrees	Geographic latitude of PSU and donor plots	Distance	CC	Exact coordinates preferred; fuzzed or grid-level coordinates acceptable where NFI confidentiality restrictions apply. May be omitted if spatial variation is negligible across donor pool
	Longitude	Lon	Decimal degrees	Geographic longitude of PSU and donor plots	Distance	CC	Same as above
Ecological / Biophysical	Ecoregion / Life zone	Eco	Categorical	Biogeographic classification	Exact match	E	Ensures environmental comparability
	Elevation	Elev	m a.s.l.	Mean elevation of plot or PSU	Distance	CC	Derived from NFI or DEM. May be omitted if elevation range is negligible
	Slope	Slope	%	Average slope of plot or PSU	Distance	CC	Derived from NFI or DEM. May be omitted if terrain variation is negligible
Forest composition	Forest type / species composition	FT	Categorical / % BA	Dominant forest type or species group composition	Exact match	E	Based on NFI or harmonized land cover
Stand structure	Basal area	BA	m^2/ha	Stand basal area	Distance	CC	Derived from DBH

	Volume	Vol	m^3/ha	Merchantable volume	Distance	CC	Derived from DBH and height
	Trees per hectare	TPH	stems/ha	Stand density	Distance	CC	From NFI field data
	Stand age / development stage	Age	years / categorical	Stand development stage	Distance	OC/OE	Use where reliable
	Additive Stand Density Index	aSDI	dimensionless	Density derived from DBH distribution	Distance	OC	Alternative stand structure metric
	Quadratic Mean Diameter	QMD	cm	Mean basal-area diameter	Distance	OC	Derived from DBH
	Canopy cover	CC	%	Percent canopy cover	Distance	OC	NFI or remote sensing
	Lorey's height	LH	m	Basal-area-weighted height	Distance	OC	Derived from height measurements
Management / tenure	Tenure class	Tenure	Categorical	Ownership or tenure classification	Exact match	E	Captures institutional drivers
	Management history / regime	Mgmt	Categorical	Past management or disturbance class	Exact match	OE	Use only where reliable
Socioeconomic / policy	Accessibility	Acc	km / categorical	Distance to roads or mills	Distance	OC	GIS derived
	Policy / regulatory context	Policy	Binary / ordinal	Harvest restrictions or protected status	Exact match	OE	Used when restrictions influence management

Table A2.3. Match Quality Decision Ladder for Donor Pool Matching.

Step	Condition	Outcome
Step 1: Standard Matching	SMD ≤ 0.25 for all required covariates using default k (e.g., k = 10)	Match deemed valid; proceed with benchmark construction
Step 2: Adjust k within bounds	If Step 1 fails, proponents must evaluate the predefined sequence of k values 10 → 7 → 5 → 3. The minimum allowable value is k = 3; values below this threshold are not permitted.	Select the first k in the predefined sequence (10 → 7 → 5 → 3) that achieves acceptable balance, provided that at least k eligible donor plots are available for the PSU. Document results for all tested k.
Step 3: Optional covariate handling	If balance remains infeasible due to optional covariates restricting overlap	Remove optional covariates sequentially; required covariates may not be removed or modified; re-run matching and document results
Step 4: Infeasibility / redesign	If balance remains infeasible after Steps 1–3	Redefine PSU boundaries or aggregation strata, or conclude that a statistically valid benchmark cannot be constructed for that PSU under this Appendix (subject to VVB review)

Table A2.4. Data and parameters available at validation for project sample units (sources of covariate values for project sample units) for Non-USA projects.

Data/Parameter	Distance to sample (treatment/project case) unit
Data unit	Kilometers
Description	Distance to sample (treatment/project case) unit
Equations	N/A
Source of data	Calculated from GIS analysis of geo-referenced locations
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Sample unit centers must be geo-referenced in the field with GPS using latitude/longitude. Where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), the relevant location is the centroid of the primary unit. "Fuzzed" (uncorrected) locations of plots recorded in the corresponding NFI can be used for the analysis.
Purpose of data	Matching / CC – Core Required Continuous
Comments	None

Data/Parameter	Lat / Lon
Data unit	Decimal degrees
Description	Latitude / Longitude. Geographic location of PSUs and donor plots
Equations	N/A
Source of data	National Forest Inventory information / GIS analysis of geo-referenced locations
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Exact coordinates preferred; fuzzed or grid-level coordinates acceptable where NFI confidentiality restrictions apply. May be omitted if spatial variation is negligible across donor pool
Purpose of data	Matching / CC – Core Required Continuous
Comments	None
Data/Parameter	Eco

Data unit	Categorical
Description	Ecoregion. Biogeographic classification
Equations	N/A
Source of data	NFI data when available or from Dinerstein, E., et al. 2017. An Ecoregion-Based Approach to Protecting Half the Terrestrial Realm, BioScience, Volume 67, Issue 6, June 2017, Pages 534–545, https://doi.org/10.1093/biosci/bix014
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Eco is used to ensure ecological comparability between project and donor plots by constraining matches to areas with similar climate, vegetation assemblages, and biophysical conditions that influence forest growth and carbon dynamics.
Purpose of data	Exact Matching (E)
Comments	None

Data/Parameter	ELEV
Data unit	Meters (in 10- or 100-meter categories)
Description	Elevation
Equations	N/A
Source of data	NFI data when available, GPS or digital elevation model
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	ELEV is determined for the sample unit location (center), or where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), ELEV is determined as the average value for the secondary units.
Purpose of data	Matching / CC – Core Required Continuous
Comments	None

Data/Parameter	SLOPE
Data unit	Percent
Description	Slope
Equations	N/A

Source of data	NFI data when available. Digital elevation model or plot-based sampling with hypsometer or clinometer (sample unit average slope)
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Where determined referencing a digital elevation model, SLOPE is determined for the sample unit location, or where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), SLOPE is determined as the area-weighted average value for the primary unit.
Purpose of data	Matching / CC – Core Required Continuous
Comments	None

Data/Parameter	FT
Data unit	Categorical / % Basal Area
Description	Forest Type
Equations	N/A
Source of data	NFI data or harmonized land cover dataset
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Constrains matching to stands with similar species composition or forest type, which affects growth dynamics, biomass allocation, and long-term carbon stock trajectories.
Purpose of data	Exact Matching (E)
Comments	None

Data/Parameter	BA
Data unit	Square meters per hectare (m^2/ha)
Description	Stand basal area
Equations	N/A
Source of data	Derive from DBH data in NFI dataset
Value applied	N/A
Justification of choice of data or description of	Basal area is used to characterize stand stocking and competitive structure, which strongly influences forest biomass and carbon

measurement methods and procedures applied	dynamics. Based on live trees measured at the minimum DBH established by the NFI.
Purpose of data	Matching / CC – Core Required Continuous
Comments	None

Data/Parameter	Vol
Data unit	Cubic meters per hectare (m^3/ha)
Description	Stand merchantable volume
Equations	N/A
Source of data	Derive from DBH data in NFI dataset.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Merchantable stand volume is used as an indicator of stand productivity and biomass stocks to ensure donor plots have comparable carbon storage conditions. Based on live trees measured at the minimum DBH established by the NFI and calculated using NFI-specific volume equations.
Purpose of data	Matching / CC – Core Required Continuous
Comments	None

Data/Parameter	TPH
Data unit	Number of stems per hectare (stems/ha)
Description	Stand density
Equations	N/A
Source of data	Derive from DBH data in NFI dataset.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Trees per hectare represents stand density and stocking level, helping ensure donor plots have comparable competitive structure and stand development conditions influencing biomass accumulation. Based on live trees measured at the minimum DBH established by the NFI.
Purpose of data	Matching / CC – Core Required Continuous
Comments	None

Data/Parameter	Age
Data unit	Years / categorical
Description	Stand age / Stand development stage
Equations	N/A
Source of data	NFI dataset if available. Stand age can also be obtained using increment cores taken at breast height from sampled trees, obtained via plot-based sampling (see description of measurement methods for live aboveground biomass, *LAG*).
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	• Stand age or development stage is used to capture differences in forest growth phase and stand dynamics that influence biomass accumulation and carbon stock trajectories. Derived from NFI stand age estimates or classified development stages where available. • Stand age calculated as average total age (age at breast height + the number of years that passed from germination until the tree reached the point of core extraction). • Stand age is estimated from increment cores from three or more representatively sampled live trees >10 cm dbh (or the minimum dbh established by the NFI), and not over-topped, from within the project sample unit. • Core each tree at the point of diameter measurement and count the rings between the outside edge and the core to the pith. Add in the number of years that passed from germination until the tree reached the point of core extraction to determine the total age of the tree. Compute the average age across all cored trees in the project sample unit.
Purpose of data	Matching / OC – Optional Continuous or OE – Optional Exact
Comments	None

Data/Parameter	aSDI
Data unit	Dimensionless
Description	Additive Stand Density Index
Equations	N/A

Source of data	NFI data is used to calculate the aSDI based on formula in Chivgenge et al. (2024).[54] Additive Stand Density Index is calculated as the sum across diameter classes of trees per hectare weighted by their relative diameter size using the Reineke self-thinning relationship.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Additive Stand Density Index is used as a structural metric of stand crowding and competitive intensity, improving comparability of stand density and growth dynamics among matched plots. Calculated from tree diameter measurements recorded in the NFI using the following equation: $$aSDI = \sum_{n=i}^{N} * Ni \left(\frac{DBHi}{25}\right)^{1.605}$$ Where: i = Index representing a diameter class or tree group in the stand. The summation runs across all diameter classes present in the stand. N = The total number of diameter classes considered in the stand. N_i = The number of trees per hectare in diameter class i DBH_i = The representative diameter at breast height (DBH) for class i(usually the class midpoint), measured in centimeters.
Purpose of data	Matching / OC – Optional Continuous
Comments	None

Data/Parameter	QMD
Data unit	centimeters (to the nearest 0.1 cm)
Description	Quadratic Mean Diameter: Diameter of tree with average basal area
Equations	N/A
Source of data	Calculated from live trees measured at the minimum DBH established by the NFI.
Value applied	N/A
Justification of choice of data or description of	Quadratic mean diameter represents the basal-area-weighted mean tree diameter and is used to characterize stand structure and size distribution influencing biomass accumulation and carbon dynamics.

[54] Chivhenge, E., Ray, D.G., Weiskittel, A.R. et al. Evaluating the Development and Application of Stand Density Index for the Management of Complex and Adaptive Forests. Curr. For. Rep. 10, 133–152 (2024). https://doi.org/10.1007/s40725-024-00212-w

measurement methods and procedures applied	
Purpose of data	Matching / OC – Optional Continuous
Comments	None

Data/Parameter	CC
Data unit	%
Description	Canopy Cover
Equations	N/A
Source of data	Derived from NFI field measurements, aerial or hemispherical photography, densiometer measurements or compatible remote sensing products where available.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Canopy cover represents the proportion of ground area covered by tree crowns and is used to characterize stand structure and forest density influencing productivity and carbon storage.
Purpose of data	Matching / OC – Optional Continuous
Comments	None

Data/Parameter	LH
Data unit	Meters (to the nearest 0.1 m)
Description	Lorey's height
Equations	N/A
Source of data	Calculated from tree height and basal area measurements recorded in the NFI.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Lorey's height provides a basal-area-weighted measure of stand height and vertical structure, improving comparability of stand development and productivity among matched plots. LH is calculated using the following equation:

	$$LH = \frac{\sum ni\ gi\ hi}{\sum ni\ gi}$$ Where: n_i = number of trees in the i^{th} diameter class, g_i = average basal area of the i^{th} diameter class, and h_i = average height of trees in the i^{th} diameter class
Purpose of data	Matching / OC – Optional Continuous
Comments	None

Data/Parameter	Tenure
Data unit	Categorical
Description	Tenure class
Equations	N/A
Source of data	Derived from national land ownership or tenure classifications associated with the NFI dataset
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Tenure class is used to capture differences in ownership or land tenure systems that influence management practices, harvesting behavior, and long-term forest carbon dynamics. Potential classes are: Private commercial ownership, Public production forest, Public conservation forest, Community / indigenous forest, Other / mixed tenure. National tenure classifications may be harmonized into these categories to ensure comparability between project and donor plots
Purpose of data	Exact Matching (E)
Comments	None

Data/Parameter	Mgmt
Data unit	Categorical
Description	Management history
Equations	N/A
Source of data	Derived from NFI records or documented disturbance classifications where available.

Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Management history or disturbance regime is used to ensure donor plots reflect comparable past management or disturbance conditions that influence stand structure and carbon stock trajectories.
Purpose of data	Optional Exact Matching (OE)
Comments	None

Data/Parameter	Acc
Data unit	Kilometers / categorical
Description	Accessibility: horizontal distance to improved road
Equations	N/A
Source of data	Derived from geospatial analysis of transportation or infrastructure datasets
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Accessibility metrics (e.g., distance to roads, mills, or infrastructure) are used as proxies for harvest pressure and operational feasibility, which influence forest management intensity and carbon stock dynamics. Calculated as the shortest straight line, overland distance from the sample unit center to the nearest improved road. An improved road is a road of any width that is maintained as evidenced by pavement, gravel, grading, ditching, and/or other improvements. Where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), the relevant location is the centroid of the primary unit.
Purpose of data	OC – Optional Continuous
Comments	None

Data/Parameter	Pol
Data unit	Binary / Ordinal
Description	Policy and regulatory context
Equations	N/A
Source of data	Derived from official protected area or regulatory datasets applicable to the project region

Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Policy or regulatory context is used to capture legal or institutional constraints on forest management that influence allowable management practices and carbon outcomes.
Purpose of data	Optional Exact Matching (OE)
Comments	None

APPENDIX 3: TESTING THE SIGNIFICANCE OF CARBON POOLS AND GHG EMISSIONS

A3.1 Description of the significance test

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 (A3.1). Where the combined significance of optional pools and emissions sources is greater than 5% proceed to Step 2 Equation (A3.2) to determine which individuals carbon pools and GHG emissions sources must be included.

Prior to compiling or processing the full NFI dataset, 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 NFI 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 the full dataset. All assumptions, data sources, and calculations used in the screening assessment must be transparently documented and subject to validation.

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

Step 1: Determine Combined Significance of E_s

$$CSR = \frac{\sum E_s}{CR} \text{ x } 100 \qquad \text{(A3.1)}$$

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 (excluding leakage) and decreases in carbon pools

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

2) 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)

$$RC_{Es} = \frac{E_s}{\sum E_s} \qquad \text{(A3.2)}$$

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.

A3.2 Equations for optional pools for Baseline and Project Scenarios

This section provides the equation forms applicable to carbon pools identified in the project boundary (see Table 1) as “Yes/Optional” (i.e., aboveground non-woody biomass, litter, soil organic carbon). Where such pools are included in the project boundary, they shall be accounted for consistently in both the baseline and project scenarios using the same calculation structure applied to mandatory pools. The equations presented herein follow the form and logic of Sections 8.1 and 8.2, with pool-specific parameters substituted as appropriate. These equations are provided for completeness and transparency and do not constitute an alternative accounting framework. Inclusion of optional pools remains subject to significance test outlined in this Appendix and the availability of consistent and comparable data for both project sample units and the composite NFI donor pool used to construct the dynamic baseline.

A3.2.1 Baseline Scenario

$$\Delta LAGnw_{bsl,i,j,mt} = (LAGnw_{bsl,i,j,t} - LAGnw_{bsl,i,j,t-X_{bsl,i,j,t}}) \times (1/X_{bsl,i,j,t}) \quad \text{A3.3}$$

$$\Delta LIT_{bsl,i,j,mt} = (LIT_{bsl,i,j,t} - LIT_{bsl,i,j,t-X_{bsl,i,j,t}}) \times (1/X_{bsl,i,j,t}) \quad \text{A3.4}$$

$$\Delta SOC_{bsl,i,j,mt} = (SOC_{bsl,i,j,t} - SOC_{bsl,i,j,t-X_{bsl,i,j,t}}) \times (1/X_{bsl,i,j,t}) \quad \text{A3.5}$$

Where:

$\Delta LAGnw_{bsl,i,j,mt}$	=	Annual change in live aboveground non-woody biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t CO_2e/unit area/year)
$LAGnw_{bsl,i,j,t}$	=	Live non-woody aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$LAGnw_{bsl,i,j,t-X\_(bsl,i,j,t)}$	=	Live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time *t* – $X_{bsl,i,j,t}$ (t CO_2e/unit area)
$\Delta LIT_{bsl,i,j,mt}$	=	Annual change in litter biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t CO_2e/unit area/year)
$LIT_{bsl,i,j,t}$	=	Litter biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$LIT_{bsl,i,j,t-X\_(bsl,i,j,t)}$	=	Litter biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time *t* – $X_{bsl,i,j,t}$ (t CO_2e/unit area)
$\Delta SOC_{bsl,i,j,mt}$	=	Annual change in soil organic carbon in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t CO_2e/unit area/year)
$SOC_{bsl,i,j,t}$	=	Soil organic carbon stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$SOC_{bsl,i,j,t-X\_(bsl,i,j,t)}$	=	Soil organic carbon stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time *t* – $X_{bsl,i,j,t}$ (t CO_2e/unit area)
$X_{bsl,i,j,t}$	=	Length of measurement interval ending at time *t* for constituent baseline plot *ij* (years)

$$\Delta LAGnw_{bsl,i,t} = \sum_{j=1}^{n} W_{bsl,i,j} \sum_{mt=-10}^{t} \Delta LAGnw_{bsl,i,j,mt} \; [t - mt < X_{bsl,i,j,t}] \qquad (A3.6)$$

$$\Delta LIT_{bsl,i,t} = \sum_{j=1}^{n} W_{bsl,i,j} \sum_{mt=-10}^{t} \Delta LIT_{bsl,i,j,mt} \; [t - mt < X_{bsl,i,j,t}] \qquad (A3.7)$$

$$\Delta SOC_{bsl,i,t} = \sum_{j=1}^{n} W_{bsl,i,j} \sum_{mt=-10}^{t} \Delta SOC_{bsl,i,j,mt} \; [t - mt < X_{bsl,i,j,t}] \qquad (A3.37)$$

Where:

$\Delta LAGnw_{bsl,i,t}$	=	Annual change in live aboveground non-woody biomass stocks in the baseline scenario at composite baseline *i* in year *t* (t CO_2e/unit area/year)
$\Delta LAGnw_{bsl,i,j,mt}$	=	Annual change in live aboveground non-woody biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t CO_2e/unit area/year)
$\Delta LIT_{bsl,i,t}$	=	Annual change in litter biomass stocks in the baseline scenario at composite baseline *i* in year *t* (t CO_2e/unit area/year)
$\Delta LIT_{bsl,i,j,mt}$	=	Annual change in litter biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t CO_2e/unit area/year)
$\Delta SOC_{bsl,i,t}$	=	Annual change in soil organic carbon in the baseline scenario at composite baseline *i* in year *t* (t CO_2e/unit area/year)
$\Delta SOC_{bsl,i,j,mt}$	=	Annual change in soil organic carbon in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t CO_2e/unit area/year)
$W_{bsl,i,j}$	=	Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1 (dimensionless)

A3.2.2 Project Scenario

$$\Delta LAGnw_{wp,i,t} = (LAGnw_{wp,i,t} - LAGnw_{wp,i,t-X_{wp,i,t}}) \times (1/X_{wp,i,t}) \qquad A3.9$$

$$\Delta LIT_{wp,i,t} = (LIT_{wp,i,t} - LIT_{wp,i,t-X_{wp,i,t}}) \times (1/X_{wp,i,t}) \qquad A3.10$$

$$\Delta SOC_{wp,i,t} = (SOC_{wp,i,t} - SOC_{wp,i,t-X_{wp,i,t}}) \times (1/X_{wp,i,t}) \qquad A3.11$$

Where:

$\Delta LAGnw_{wp,i,t}$	=	Average annual change in live aboveground non-woody biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area/year)

$LAGnw_{wp,i,t}$	=	Live aboveground non-woody biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$LAGnw_{wp,i,t\text{-}X\_(wp,i,t)}$	=	Live aboveground non-woody biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time $t - X_{wp,i,t}$ (t CO_2e/unit area)
$\Delta LIT_{wp,i,t}$	=	Average annual change in litter biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area/year)
$LIT_{wp,i,t}$	=	Litter biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$LIT_{wp,i,t\text{-}X\_(wp,i,t)}$	=	Litter biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time $t - X_{wp,i,t}$ (t CO_2e/unit area)
$\Delta SOC_{wp,i,t}$	=	Average annual change in soil organic carbon stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area/year)
$SOC_{wp,i,t}$	=	Soil organic carbon stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO_2e/unit area)
$SOC_{wp,i,t\text{-}X\_(wp,i,t)}$	=	Soil organic carbon stocks in the project scenario in sample unit *i* in the monitoring interval ending at time $t - X_{wp,i,t}$ (t CO_2e/unit area)
$X_{wp,i,t}$	=	Length of measurement interval ending at time *t* for sample unit *i* in the project scenario (years)

In cases where optional pools (i.e., aboveground non-woody biomass, litter, soil organic carbon) are included, carbon stock change in the project scenario is then estimated for each sample unit *i* in year *t* using a modified version of Equation (23) as follows:

$$\Delta CO2_{wp,i,t} = \Delta LAG_{wp,i,t} + \Delta LBG_{wp,i,t} + \Delta DW_{wp,i,t} + HWP_{wp,i,t} + \Delta LAGnw_{wp,i,t} + \Delta LIT_{wp,i,t} + \Delta SOC_{wp,i,t} \quad \text{(A3.12)}$$

DOCUMENT HISTORY

Version	Date	Comment
v1.0	26 Oct 2022	Initial version
v1.1	12 Mar 2024	• Separation of GHG emission reductions and carbon dioxide removals in Section 8 • Minor clarifications and edits
C&C Issued for v1.1	13 Dec 2024	• Corrections to Equations 30 to 34
v1.2	10 Jul 2025	• Alignment with the requirements of the Core Carbon Principles (CCP) Assessment Framework of the Integrity Council for the Voluntary Carbon Market (ICVCM) • Clarification of the FIA data collection process (Appendix 1, Section A1.3) • Clarification of the significance of carbon pools (Tables 1 and 2) and inclusion of Appendix 2 to test significance • Updates to Section 9.3 (Description of the Monitoring Plan) to require projects to provide confirmation of mitigation activities • Correction to Equation A2 to calculate the standardized difference of means during the match quality assessment • Clarifications to Table A.1 regarding required covariates for Obtaining Matches of Composite Baselines from USFS FIA plot, including elevation as “optional” • General edits for clarity
v1.3 consultation draft	12 May 2026	• General update of language to reflect the new international scope of VM0045 • New Appendix 2 added includes the procedures for non-US projects to use VM0045 • Previously Appendix 2 (testing the significance of carbon pools and GHG emissions) is now Appendix 3. Clarified procedures for preliminary screening of carbon pool significance using literature values or partial NFI data. Included equations for optional carbon pools. • General typesetting and edits for clarity