VCS Methodology

VM0047

AFFORESTATION, REFORESTATION AND REVEGETATION

Version 1.0 - Greenlined

14 May 2025

Sectoral Scope 14

CONTENTS

1 SOURCES

This methodology is based on the following methodology:

- *AR-ACM0003 A/R Large-scale Consolidated Methodology: Afforestation and Reforestation of Lands Except Wetlands*

Portions of this methodology are based on the following modules and tools:

- *Tool for testing significance of GHG emissions in A/R CDM project activities*

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

2 SUMMARY DESCRIPTION OF THE METHODOLOGY

Additionality and Crediting Method[1]	
Additionality	Performance Method or Project Method
Crediting Baseline	Performance Method or Project Method

The methodology applies to afforestation, reforestation, and revegetation (ARR) activities and provides two quantification approaches: area-based and census-based. Project activities must establish, increase, or restore vegetative cover in non-forest areas (applicable to both approaches), or activities must enhance forest carbon stocks in areas with existing forest cover that have not been managed for wood products in the past ten years (applicable to the area-based approach only).

1) Area-based approach:

a) uses traditional plot-based sampling methods that scale biomass estimates per unit area to the project level using project area as the multiplier (i.e., the area within the project boundary).

b) uses a dynamic performance benchmark to demonstrate additionality and determine the crediting baseline at every verification. The performance benchmark

---

[1] See Section 0 and Section 7 for additional information

is calculated from ex-post observations of business-as-usual changes in vegetative cover in matched control areas.

   c) The area-based approach applies to ARR projects that change land cover from non-forest to forest or enhance stocks in existing forests. Projects may include direct (e.g., manual planting, broadcast seeding) and indirect activities (e.g., activities that permit or facilitate natural regeneration, like herbivory exclosures).

2) **Census-based approach:**

   a) is applicable where the project activity does not result in a change in land use and where a complete census of plantings is practical (e.g., urban forestry, agroforestry, forest shelterbelts, plantings directed to rural homesteads, revegetation not meeting the forest definition);

   b) ARR project activities must be direct plantings;

   c) scales biomass by planting unit to the project level using a complete census of planting units (i.e., the project boundary is defined by the individual planting units);

   d) uses a project method to demonstrate additionality and determine the crediting baseline.

The most current version of *VMD0054 Module for estimating leakage from ARR activities* must be applied in conjunction with this methodology. It provides a standardized approach to account for leakage related to the displacement of pre-project agricultural activities caused by the baseline agent (activity-shifting leakage) or other actors (market leakage).

3   DEFINITIONS

In addition to the definitions set out in the latest version of the *VCS Program Definitions*, the following definitions apply to this methodology.

Donor pool area
Geospatial domain with similar attributes to project plot, within which control plots may be selected

Managed forests

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

Matching covariates

Continuous variables on which control plots are matched to each project plot, minimally including historical and initial stocking indices (SI)

Multivariate distance metric

Metric that computes the distance between two vectors (e.g., Mahalanobis distance). Used to quantify the match or "closeness" between prospective control plots and project plots

Planting unit

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

Control plot

Plots located outside of the project area that are selected based on their similarity to project plots and on which stocking index is monitored over the crediting period via remote sensing

Project plot

Plots of up to 10 ha representatively sampled from the project area and on which the stocking index (SI) is evaluated via remote sensing

Stocking index (SI)

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

Woody biomass

Biomass in plants with hard, lignified stems, for example, trees, shrubs, palms and bamboo

4 APPLICABILITY CONDITIONS

This methodology applies to ARR activities.

The following applicability conditions apply to both area and census-based approaches:

The methodology is applicable under the following conditions:

1) Project activities increase vegetative cover; and

2) Area based, census based, or a combination of the two quantification approaches may be used provided approach-specific applicability conditions are met. Approaches must be selected at the project start date and used for the entire project crediting period. Where the two approaches are used together, they must be applied in non-overlapping areas defined

at the project start (see Section 5 on delineation of spatial boundaries to ensure non-overlap).

This methodology is not applicable under the following conditions:

3) Project activities involve mechanical removal offsite or burning of significant[2] stocks of pre-existing dead wood (e.g., for site preparation). Where project site preparation includes chipping, mastication or machine piling, all material must remain onsite within the project boundary.

4) Project activities take place in tidal wetlands (e.g., mangroves, salt marshes).

5) Project activities that occur on organic soils or in wetlands and result in a manipulation of the water table. Planting species that do not naturally occur in organic soils or wetlands is considered a manipulation of the water table. Where projects take place on organic soils or wetlands and manipulate the water table, they must be developed using a multiple project activity design applying this methodology and a Wetland Restoration and Conservation methodology (e.g., *VM0036 Methodology for Rewetting Drained Temperate Peatlands*). In such cases, the project activities must comply with all applicable conditions of the selected Wetland Restoration and Conservation methodology and this methodology.

6) The project occurs on lands that have met the definition of managed forest at any point in the 10-year period immediately preceding the project start date.

The following additional applicability conditions specific to the area-based and census-based approaches must be met:

Area-based approach

6)7) Project activities produce continuous tree and/or shrub cover on any contiguous area exceeding one hectare.

7)8) Projects may include direct (e.g., manual planting, broadcast seeding) and indirect activities (e.g., activities that permit or facilitate natural regeneration, like herbivory exclosures).

Census-based approach

8)9) Project activity must be direct planting (i.e., must not involve facilitated natural regeneration)

9)10) Project activity must not produce continuous tree and/or shrub cover on any contiguous area exceeding one hectare.

---

[2] Significance determined by applying procedures in Appendix 2

10)11) Individual planting units of woody biomass must be clearly defined (e.g., tree, shrub, bamboo clump) and identifiable in the field, with each planting unit given a physical marker onsite with a unique ID and location recorded by GPS with a minimum accuracy of five meters[3]

11)12) Project activity must:

  a) occur within an area classified as non-forest for the past ten years with less than 10% percent pre-existing woody biomass cover; and/or

  b) occur in an area subject to continuous cropping[4], in "settlements", or "other lands" land use category[5]

12)13) An initial complete census of all planting units at t=0 must be conducted

13)14) Projects are considered ineligible if woody biomass, which serves a similar purpose as the planting units in the project, has been removed within the last ten years (confirmed via pre-project photos and/or attestation)

14)15) Any soil disturbance from the project activity (i.e., from site preparation):

  a) occurs only once during the project crediting period (i.e., at site preparation); or

  b) does not involve soil inversion to a depth exceeding 25 cm (e.g., that would result from a moldboard plow).

5 PROJECT BOUNDARY

Project proponents must apply the area-based or census-based approach or a combination of the two. The approach must be selected at the project start date and used for the entire project crediting period. Where both approaches are used, they must be applied in non-overlapping areas defined at the project start.

Area-based approach

---

[3] Based on growth traits of planted species, individual planting unit crowns are unlikely to expand beyond 10 meters radius from their originally established location.

[4] i.e., cultivation of an agricultural crop on the same site year after year, without any periods of fallow exceeding one season, demonstrated over 10 or more years prior to the project start date

[5] Land use category as defined by the *IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 AFOLU, Chapter 3 Consistent Representation of Lands.

For the area-based quantification approach, the spatial extent of the project boundary encompasses all lands subject to implementation of the ARR project activity. Requirements regarding delineation of the project boundary and estimation of the project area, A, are provided in Section 9.1.

Selected carbon pools included in the project boundary in the area-based baseline and project scenarios are listed in Table 1.

Census-based approach

The relevant spatial boundary for the census-based approach is a 10-meter radius buffer around the recorded GPS location of each planting unit. This is required to ensure accounting boundaries do not overlap when area-based and census-based approaches are used in the same project. This spatial boundary will also be used to assess VCS eligibility and methodology applicability conditions. In the census-based approach, a project area is not used for scaling estimated carbon stocks. Scaling is based on the number of planting units, N_t.

Selected carbon pools included in the project boundary in the census-based baseline and project scenarios are listed in Table 2.

Carbon pools and GHG emissions sources may be deemed de minimis where it can be reasonably demonstrated that the combined decrease in carbon stocks or increase in GHG emissions amounts to less than five percent of the total GHG benefit generated by the project. Appendix 2 of this methodology must be applied to demonstrate that the decrease in carbon stocks or increase in GHG emissions together amount to less than five percent of the total GHG benefit generated by the project.

Table 1: Selected Carbon Pools in the Project Boundary Using the Area-based Approach

Carbon Pool	Included?	Justification/Explanation
Aboveground woody biomass	Yes	Major carbon pool
Aboveground non-woody biomass	Yes/Optional	Must be included if the project activity significantly reduces the carbon pool as per Appendix B. For other cases this carbon pool is optional.
Belowground woody biomass	Yes	Major carbon pool
Belowground non-woody biomass	Yes/Optional	Must be included if the project activity significantly reduces the carbon pool as per Appendix B. For other cases this carbon pool is optional.
Dead wood	Optional	Carbon stock in this pool may increase due to implementation of the project activity
Litter	Yes/Optional	Must be included if the project activity significantly reduces the carbon pool (i.e., is not determined to be de minimis).

		For other cases this carbon pool is optional.
Soil organic carbon (SOC)	Yes/Optional	Must be included where soil disturbance from the project activity (i.e., from site preparation): 1) Occurs more than once during the project crediting period (i.e., at site preparation); or 2) Involves soil inversion to a depth exceeding 25 cm (e.g., that would result from a moldboard plow). Where the project activity does not cause soil disturbance the inclusion of this carbon pool is optional.
Harvested wood products	Excluded	Conservative to exclude

Table 2: Selected Carbon Pools in the Project Boundary using the Census-based Approach

Carbon Pool	Included?	Justification/Explanation
Aboveground woody biomass	Yes	Major carbon pool
Aboveground non-woody biomass	Excluded	Conservative to exclude
Belowground woody biomass	Yes	Major carbon pool
Belowground non-woody biomass	Excluded	Conservative to exclude
Dead wood	Excluded	Conservative to exclude
Litter	Excluded	Conservative to exclude
Soil organic carbon (SOC)	Excluded	Conservative to exclude
Harvested wood products	Excluded	Conservative to exclude

The greenhouse gases included in or excluded from the project boundary are shown in Table 3.

Table 3: GHG Sources Included In or Excluded From the Project Boundary

Source	Gas	Included?	Justification/Explanation
Baseline	CO_2	No	Conservative to exclude
	CH_4	No	Conservative to exclude

	Burning of biomass (whether by natural or anthropogenic causes)	N_2O	No	Conservative to exclude
	Emissions from nitrogen fertilizer	CO_2	No	Conservative to exclude
		CH_4	No	Conservative to exclude
		N_2O	No	Conservative to exclude
	Burning of fossil fuels	CO_2	No	Conservative to exclude
		CH_4	No	Conservative to exclude
		N_2O	No	Conservative to exclude
Project	Burning of biomass (natural or anthropogenic causes)	CO_2	No	Carbon stock decreases due to burning are accounted as a carbon stock change
		CH_4	Yes	May be a significant source
		N_2O	Yes	May be a significant source
	Emissions from nitrogen fertilizer	CO_2	No	Conservative to exclude
		CH_4	No	Conservative to exclude
		N_2O	Yes	May be a significant source
	Burning of fossil fuels	CO_2	No	De minimis
		CH_4	No	De minimis
		N_2O	No	De minimis

6 BASELINE SCENARIO

Area-based approach

A performance benchmark is used to set the crediting baseline. The performance benchmark, defined as the business-as-usual increase in vegetative cover relative to the project, is set based on data from representative control plots outside of the project area.

Procedures to establish the performance benchmark are provided in Appendix 1.

Census-based approach

The census-based quantification approach uses a project method for setting the crediting baseline. The project activity must:

1) occur within an area with pre-existing woody biomass cover of less than ten percent; and/or

2) occur in an area subject to continuous cropping, in settlement(s), or on lands categorized as 'other lands'.

If the project meets these criteria, it can be assumed that afforestation, reforestation, or revegetation will not occur without project interventions and the crediting baseline may be set to zero. All other baselines are effectively excluded from being applied.

7   ADDITIONALITY

The projects must apply a performance method (area-based approach) or a project method (census-based approach) for the demonstration of additionality.

Area-based approach

Projects using the area-based approach must apply the following steps to demonstrate additionality:

> Step 1: Regulatory surplus
>
> Step 2: Performance benchmark
>
> Step 3: Investment barrier

Project must apply Step 3 only when there are revenues or financial incentives other than from the sales of carbon credits.

Census-based approach

Projects using the census-based approach must apply the following steps to demonstrate additionality:

> Step 1: Regulatory surplus
>
> Step 3: Investment barrier
>
> Step 4: Common practice

Step 1: Regulatory Surplus

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

Step 2: Performance Benchmark

The performance benchmark must be established following the procedures in Appendix 1. Only projects using the area-based quantification approach are eligible to use the performance benchmark approach to additionality.

Where parameters $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$ are deemed significantly different (via Z test in Appendix 1 Equation (A5)), the project demonstrates additionality for the performance benchmark.

To demonstrate additionality at validation projects must apply an ex-ante calculation to demonstrate an expected difference between modelled performance of the project and the forecasted performance benchmark. Area-based projects must reassess additionality using the Z test in Appendix 1, Equation (A5), at every verification.

Step 3: Investment Barrier

Methodologies applying an investment barrier analysis to assess additionality must select a benchmark analysis or investment comparison analysis. Project proponents must apply the procedures and requirements in the latest version of the *VCS Methodology Requirements*.[6]

Step 4: Common Practice

When using census-based approach, the following steps must be taken to demonstrate that without carbon finance project activity would not be common practice:

1) Define the ARR project activity (e.g., tree planting).

2) Identify the geographic domain with similar policy (and market, as available) environment as the project area. The geographic domain is first defined as the national boundary. If national or sub-national programs provide incentives for afforestation, reforestation, or revegetation activities at the subnational level, the geographic domain must be further constrained to reflect similar incentives and market conditions as those presented in the project area (e.g., proximity to nurseries or wood processing infrastructure).

3) Identify a similar class of adopters or landowners (e.g., smallholder farmers).

4) Survey a representative sample of similar landowners from within the relevant geographic domain within five years of the project start date.

5) Calculate the (cumulative) adoption rate (%) of the project activity of landowners who have not received carbon finance revenue (e.g., not part of a registered VCS AFOLU project) in the sample of the adopter class.

Where the adoption rate is below 15% (Mathur et al., 2007), the project activity is not common

---

[6] At the time of approval of this methodology, *VCS Methodology Requirements v4.4* is the most recent version. The relevant procedures and requirements for the investment analysis are in included in section 3.5.5 of this version. Projects must use the most recent version of the *VCS Methodology Requirements*.

practice. Where the adoption rate equals or exceeds 15%, the project activity is common practice and is not additional.

Alternatively, relevant government statistics on afforestation, reforestation, and revegetation activities relevant to the project area (that do not distinguish activities incentivized by carbon finance and thus are conservative) may be used for this demonstration, provided they are derived from data collected from within five years of the project start date.

8 QUANTIFICATION OF ESTIMATED REMOVALS

8.1 Baseline

Area-based approach

Carbon stock changes in the baseline scenario are accounted for by applying the crediting baseline performance benchmark value (derived in Section 6) to the estimation of carbon dioxide removals (Section 8.5).

Census-based approach

The baseline scenario is represented by the absence of the planting units, and carbon stock changes in the baseline scenario are equal to zero.

8.2 Project

The calculations of carbon stock changes and project emissions differ by quantification approach, summarized in Figure 1 (area-based approach) and Figure 2 (census-based approach).

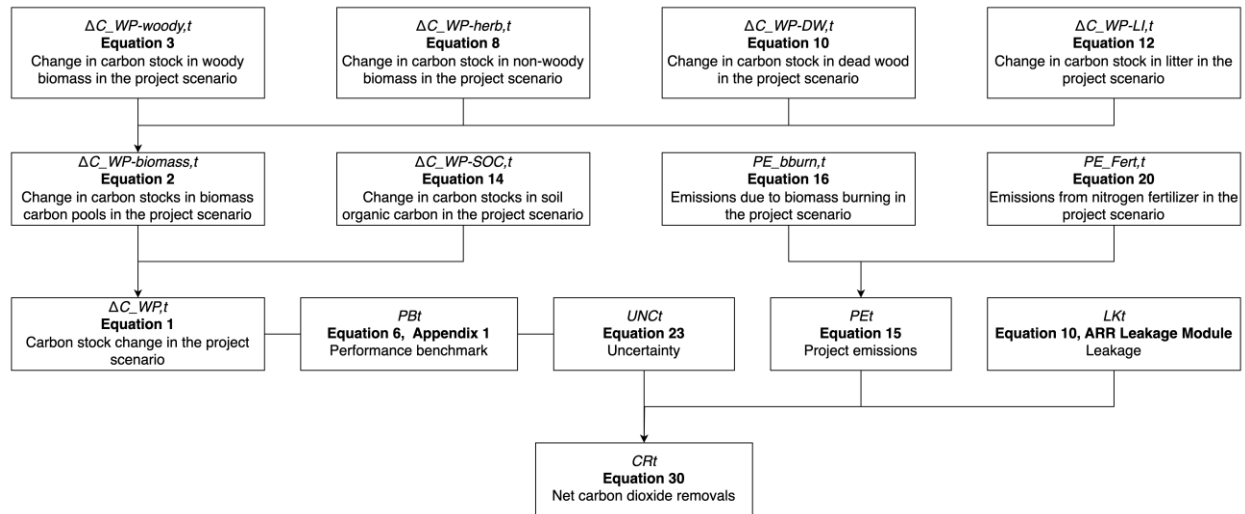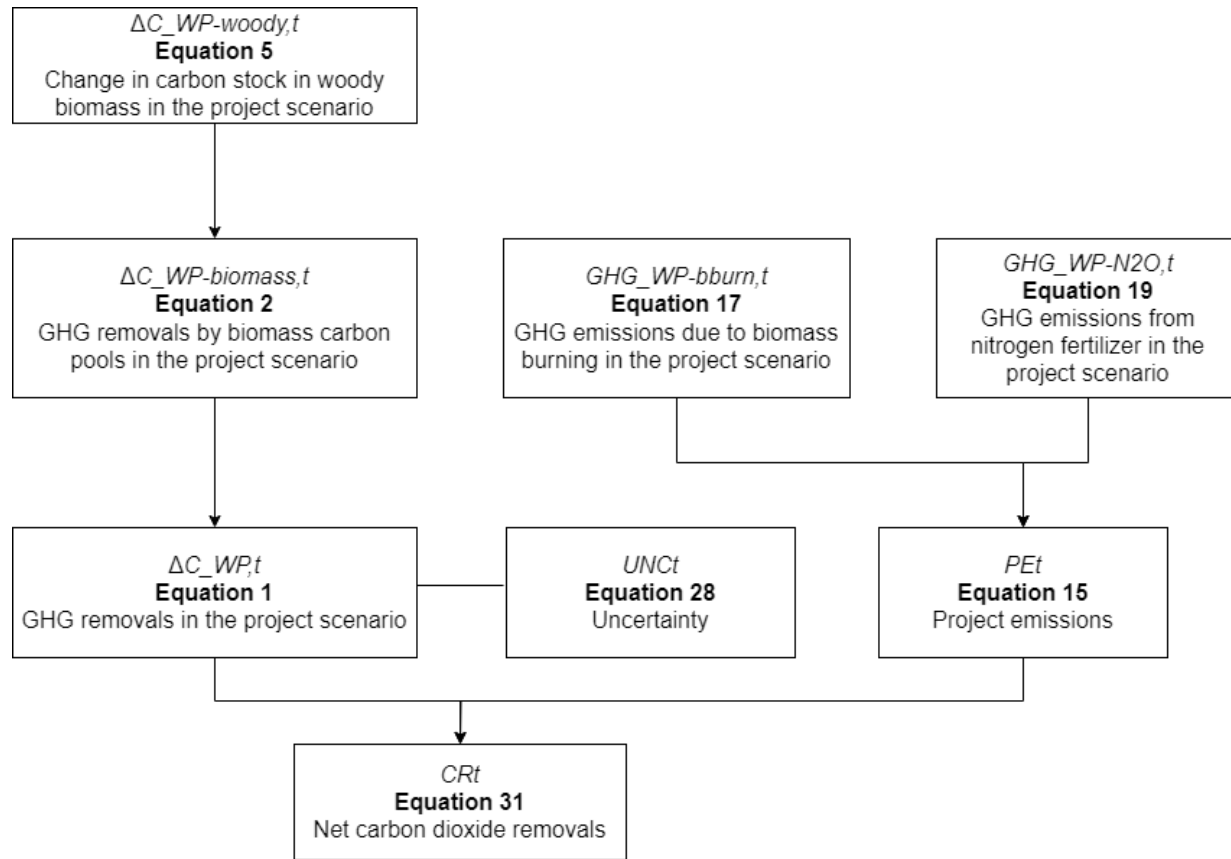**Figure 1: Summary of Calculations for Area-based Approach**

| $\Delta C\_WP\text{-}woody,t$ **Equation 3** Change in carbon stock in woody biomass in the project scenario | $\Delta C\_WP\text{-}herb,t$ **Equation 8** Change in carbon stock in non-woody biomass in the project scenario | $\Delta C\_WP\text{-}DW,t$ **Equation 10** Change in carbon stock in dead wood in the project scenario | $\Delta C\_WP\text{-}LI,t$ **Equation 12** Change in carbon stock in litter in the project scenario |

| $\Delta C\_WP\text{-}biomass,t$ **Equation 2** Change in carbon stocks in biomass carbon pools in the project scenario | $\Delta C\_WP\text{-}SOC,t$ **Equation 14** Change in carbon stocks in soil organic carbon in the project scenario | PE_bburn,t **Equation 16** Emissions due to biomass burning in the project scenario | PE_Fert,t **Equation 20** Emissions from nitrogen fertilizer in the project scenario |

| $\Delta C\_WP,t$ **Equation 1** Carbon stock change in the project scenario | PBt **Equation 6, Appendix 1** Performance benchmark | $UNCt$ **Equation 23** Uncertainty | PEt **Equation 15** Project emissions | LKt **Equation 10, ARR Leakage Module** Leakage |

CRt
Equation 30
Net carbon dioxide removals

Figure 2: Summary of Calculations for Census-based Approach.

$\Delta C\_WP\text{-}woody,t$
Equation 5
Change in carbon stock in woody biomass in the project scenario

| $\Delta C\_WP\text{-}biomass,t$ **Equation 2** GHG removals by biomass carbon pools in the project scenario | $GHG\_WP\text{-}bburn,t$ **Equation 17** GHG emissions due to biomass burning in the project scenario | $GHG\_WP\text{-}N2O,t$ **Equation 19** GHG emissions from nitrogen fertilizer in the project scenario |

| $\Delta C\_WP,t$ **Equation 1** GHG removals in the project scenario | $UNCt$ **Equation 28** Uncertainty | PEt **Equation 15** Project emissions |

CRt
Equation 31
Net carbon dioxide removals

Leakage and performance benchmark are not included in calculations (implicitly set equal to zero), soil organic carbon is excluded, and biomass carbon is restricted to (live) woody biomass.

8.2.1   Project Carbon Stock Changes

The carbon stock change from the start of the project through year t is estimated as follows:

(1)

$$\Delta C_{WP,t} = (\Delta C_{WP-biomass,t} + \Delta C_{WP-SOC,t}) \times \frac{44}{12}$$

Where:

$\Delta C_{WP,t}$	=	Project carbon stock change through year t (t CO$_2$e)
$\Delta C_{WP\text{-}biomass,t}$	=	Change in carbon stock in biomass carbon pools in the project scenario through year t (t C)
$\Delta C_{WP\text{-}SOC,t}$	=	Change in SOC stock in the project scenario through year t (t C)
44/12	=	Ratio of molecular weight of carbon dioxide to carbon (unitless)
t	=	1, 2, 3, …, t years elapsed since the project start date

$$\Delta C_{WP-biomass,t} = \Delta C_{WP-woody,t} + \Delta C_{WP-herb,t} + \Delta C_{WP-DW,t} + \Delta C_{WP-LI,t}$$

(2)

Where:

$\Delta C_{WP\text{-}biomass,t}$	=	Change in carbon stock in biomass carbon pools in the project scenario through year t (t C)
$\Delta C_{WP\text{-}woody,t}$	=	Change in carbon stock in woody biomass in the project scenario through year t (t C)
$\Delta C_{WP\text{-}herb,t}$	=	Change in carbon stock in non-woody biomass in the project scenario through year t (t C)
$\Delta C_{WP\text{-}DW,t}$	=	Change in carbon stock in dead wood in the project scenario through year t (t C)
$\Delta C_{WP\text{-}LI,t}$	=	Change in carbon stock in litter in the project scenario through year t (t C)
t	=	1, 2, 3, …, t years elapsed since the project start date

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

Projects using the area-based quantification approach may initiate accounting (i.e., project plot sampling) after the project start date provided that:

1) Soil disturbance from site preparation did not involve soil inversion to a depth exceeding 25 cm (e.g., that would result from a moldboard plow), and

2) Site preparation does not involve significant reductions of woody biomass (see Section 8.2.1.1 for details on pre-existing woody biomass).

Where projects establish initial stocks at $t > 0$, the year of initial measurement is substituted for $t=0$ in all project stock change equations calculating stock change through year t. Note, this does not affect the project start date which remains as $t=0$.

8.2.1.1 Woody Biomass

Area-based quantification

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

$$\Delta C_{WP-woody,t} = A \times (C_{WP-woody,t} - C_{WP-woody,t=0}) \tag{3}$$

Where:

$\Delta C_{WP\text{-}woody,t}$	=	Change in carbon stock in woody biomass in the project scenario through year t (t C)
A	=	Area (ha)
$C_{WP\text{-}woody,t}$	=	Average carbon stock in woody biomass in the project scenario in year t (t C/ha)
t	=	1, 2, 3, …, t years elapsed since the project start date

$$C_{WP-woody,t} = C_{WP-woody-AB,t} \times (1 + R) \tag{4}$$

Where:

$C_{WP\text{-}woody,t}$	=	Average carbon stock in woody biomass in the project scenario in year t (t C/ha)
$C_{WP\text{-}woody\text{-}AB,t}$	=	Average carbon stock in aboveground woody biomass in the project scenario in year t (t C/ha)
R	=	Root to shoot ratio (t root d.m./t shoot d.m.)
t	=	1, 2, 3, …, t years elapsed since the project start date

The change in carbon stock in woody biomass is estimated using the stock difference method (Bird, et. al., 2010), which estimates the difference in carbon stocks at two points in time.

Pre-existing woody biomass

Pre-existing woody biomass must be measured and extrapolated using Equation (4) at $t=0$, immediately prior to initiation of the project activity (e.g., before site preparation). Where initial stocks are measured at $t > 0$, pre-existing woody biomass is equal to the initial stock

measurement. Any clearing of pre-existing woody biomass as part of the project activity (e.g., due to site preparation) must be estimated using the stock difference method. Where the slope of a linear regression of stocking index values (see Appendix 1) from time $t= -10$ to $t=0$, including site preparation, is significant and negative, clearing of pre-existing biomass is indicated. In this case, the project proponent must demonstrate that the clearing did not take place to create GHG credits as follows:

1) The prior clearing was the result of natural disturbances such as fires, hurricanes, or floods (e.g., using aerial imagery); or

2) The prior clearing was conducted by actors with no relationship to the project proponent or landowner (e.g., via community surveys or law enforcement records); or

3) The consideration of carbon finance post-dated and did not incentivize the clearing event (e.g., via a feasibility study, communications with a carbon project developer, or community surveys indicating little local knowledge or engagement on carbon projects at the time of the clearing).

Where it is not possible to provide such evidence, the project is ineligible.

Census-based quantification

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

$$\Delta C_{WP-woody,t} = C_{WP-woody,t}$$

(5)

Where:

$\Delta C_{WP\text{-}woody,t}$	=	Change in carbon stock in woody biomass in the project scenario through year t (t C)
$C_{WP\text{-}woody,t}$	=	Average carbon stock in woody biomass in the project scenario in year t (t C)
t	=	1, 2, 3, ..., t years elapsed since the project start date

Carbon stock in woody biomass in the project scenario is estimated by applying the number of planting units as a scaling factor, N, to the complete census of planting units (not monitored) adjusted for mortality, M_t, at each monitoring event.

$$C_{WP-woody,t} = N \times (1 - M_t) \times C_{WP-woody,pu\_avg,t}$$

(6)

Where:

$C_{WP\text{-}woody,t}$	=	Average carbon stock in woody biomass in the project scenario in year t (t C)
N	=	Initial population size (number of planting units)

M_t	=	Mortality through year t (percent)
$C_{WP\text{-}woody\text{-}pu\_avg,t}$	=	Average carbon stock in woody biomass per planting unit (pu) in the project scenario in year t (t C/pu)
t	=	1, 2, 3, …, t years elapsed since the project start date

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

$$C_{WP-woody-pu\_avg,t} = \frac{1}{n_t} \times \sum_{pu=1}^{n_t} (B_{WP-woody-AB,pu,t} \times (1+R) \times CF) \tag{7}$$

Where:

$C_{WP\text{-}woody\text{-}pu\_avg,t}$	=	Average carbon stock in woody biomass per planting unit (pu) in the project scenario in year t (t C/pu)
n_t	=	Number of planting units sampled in year t (integer)
$B_{WP\text{-}woody\text{-}AB,pu,t}$	=	Estimated biomass stock in aboveground woody biomass in sampled planting unit pu in the project scenario in year t (t d.m.)
R	=	Root to shoot ratio (t root d.m./t shoot d.m.)
CF	=	Carbon fraction of dry biomass (t C/t d.m.)
t	=	1, 2, 3, …, t years elapsed since the project start date

8.2.1.2   Non-Woody Biomass

Area-based quantification

$$\Delta C_{WP-herb,t} = A \times (C_{WP-herb,t} - C_{WP-herb,t=0}) \tag{8}$$

$$C_{WP-herb,t} = DM_{WP-herb,t} \times CF \tag{9}$$

Where:

$\Delta C_{WP\text{-}herb,t}$	=	Change in carbon stock in non-woody biomass in the project scenario through year t (t C)
A	=	Area (ha)
$C_{WP\text{-}herb,t}$	=	Average carbon stock in non-woody biomass in the project scenario in year t (t C/ha)
$DM_{WP\text{-}herb,t}$	=	Average non-woody biomass in the project scenario in year t (t d.m./ha)
CF	=	Carbon fraction of dry biomass (t C/t d.m.)
t	=	1, 2, 3, …, t years elapsed since the project start date

Census-based quantification

Not Applicable.

20

8.2.1.3 Dead Wood

Area-based quantification

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

$$\Delta C_{WP-DW,t} = A \times (C_{WP-DW,t} - C_{WP-DW,t=0}) \tag{10}$$

Where:

$\Delta C_{WP\text{-}DW,t}$	=	Change in carbon stock in dead wood in the project scenario through year t (t C)
A	=	Area (ha)
$C_{WP\text{-}DW,t}$	=	Average carbon stock in dead wood in year t (t C/ha)
t	=	1, 2, 3, …, t years elapsed since the project start date

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

$$C_{WP-DW,t} = (B_{SDW,t} + B_{LDW,t}) \times CF \tag{11}$$

Where:

$C_{WP\text{-}DW,t}$	=	Average carbon stock of dead wood in year t (t C/ha)
$B_{SDW,t}$	=	Average biomass of standing dead wood in year t (t d.m./ha)
$B_{LDW,t}$	=	Average biomass of lying dead wood in year t (t d.m./ha)
CF	=	Carbon fraction of dry biomass (t C/t d.m.)
t	=	1, 2, 3, …, t years elapsed since the project start date

Census-based quantification

Not applicable.

8.2.1.4 Litter

Area-based quantification

$$\Delta C_{WP-LI,t} = A \times (C_{WP-LI,t} - C_{WP-LI,t=0}) \tag{12}$$

Where:

$\Delta C_{WP\text{-}LI,t}$	=	Change in carbon stock in litter in the project scenario through year t (t C)
A	=	Area (ha)

| $C_{WP\text{-}LI,t}$ | = | Average carbon stock in litter in the project scenario in year t (t C/ha) |
| t | = | 1, 2, 3, ..., t years elapsed since the project start date |

$$C_{WP-LI,t} = DM_{WP-LI,t} \times CF \tag{13}$$

Where:

$C_{WP\text{-}LI,t}$	=	Average carbon stock in litter in the project scenario in year t (t C/ha)
$DM_{WP\text{-}LI,t}$	=	Average litter dry mass per hectare in the project scenario in year t (t d.m./ha)
CF	=	Carbon fraction of dry biomass (t C/t d.m.)
t	=	1, 2, 3, ..., t years elapsed since the project start date

Census-based quantification

Not applicable.

8.2.1.5   Soil Organic Carbon

Area-based quantification

Stocks of soil organic carbon (SOC) are estimated from direct measurements. The change in SOC stock in the project scenario is estimated as:

$$\Delta C_{WP-SOC,t} = A \times (C_{WP-SOC,t} - C_{WP-SOC,t=0}) \tag{14}$$

Where:

$\Delta C_{WP\text{-}SOC,t}$	=	Change in carbon stock in SOC in the project scenario through year t (t C)
A	=	Area (ha)
$C_{WP\text{-}SOC,t}$	=	Average SOC stock in year t (t C/ha)
t	=	1, 2, 3, ..., t years elapsed since the project start date

Census-based quantification

Not applicable.

8.2.2   Project emissions

Project emissions resulting from biomass burning and use of fertilizer in the area- or census-based approach are estimated as:

$$PE_t = PE_{bburn,t} + PE_{fert,t} \tag{15}$$

Where:

PE_t = Project emissions from biomass burning and fertilizer in the monitoring interval ending in year t (t CO_2e)

$PE_{bburn,t}$ = Project emissions due to biomass burning in the monitoring interval ending in year t (t CO_2e)

$PE_{fert,t}$ = Project emissions from nitrogen fertilizer in the monitoring interval ending in year t (t CO_2e)

8.2.2.1 Emissions from Biomass Burning

Area-based quantification

$$PE_{bburn,t} = A_{burn,t} \times \sum_{g=1}^{G}(GWP_g \times EF_g \times B_{WP,t} \times COMF \times 10^{-3}) \tag{16}$$

Where:

$PE_{bburn,t}$ = Project emissions due to biomass burning in the monitoring interval ending in year t (t CO_2e)

$A_{burn,t}$ = Area burned in the monitoring interval ending in year t (ha)

GWP_g = Global warming potential for gas g (dimensionless)

EF_g = Emission factor for gas g (kg gas/t d.m. burned)

$B_{WP,t}$ = Average aboveground biomass stock subject to burning in the project scenario in the monitoring interval ending in year t (t d.m./ha)

$COMF$ = Combustion factor (dimensionless)

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

g = 1, ..., G greenhouse gases (methane and nitrous oxide) (dimensionless)

10^{-3} = Conversion of kg CO_2e to tCO_2e

The average aboveground biomass stock subject to burning is estimated as follows:

$$B_{WP,t} = (C_{WP-woody-AB,t-\Delta t} + C_{WP-herb,t-\Delta t} + C_{WP-DW,t-\Delta t} + C_{WP-LI,t-\Delta t}) \times (1/CF) \tag{17}$$

Where:

$B_{WP,t}$	=	Average aboveground biomass stock subject to burning in the project scenario in the monitoring interval ending in year t (t d.m./ha)
$C_{WP\text{-}woody\text{-}AB,t\text{-}\Delta t}$	=	Average carbon stock in aboveground woody biomass in the project scenario in year $t - \Delta t$ (t C/ha)
$C_{WP\text{-}herb,t\text{-}\Delta t}$	=	Average carbon stock in non-woody biomass in the project scenario in year $t - \Delta t$ (t C/ha)
$C_{WP\text{-}DW,t\text{-}\Delta t}$	=	Average carbon stock in dead wood in year $t - \Delta t$ (t C/ha)
$C_{WP\text{-}LI,t\text{-}\Delta t}$	=	Average carbon stock in litter in the project scenario in year $t - \Delta t$ (t C/ha)
CF	=	Carbon fraction of dry biomass (t C/t d.m.)
t	=	1, 2, 3, ..., t years elapsed since the project start date
Δt	=	Length of monitoring interval ending in year t (years)

Census-based quantification

$$PE_{bburn,t} = \sum_{g=1}^{G} (GWP_g \times EF_g \times B_{WP,t} \times COMF \times 10^{-3}) \tag{18}$$

Where:

GWP_g	=	Global warming potential for gas g (dimensionless)
EF_g	=	Emission factor for gas g (kg/t d.m. burned)
$B_{WP,t}$	=	Aboveground biomass stock subject to burning in the project scenario in the monitoring interval ending in year t (t d.m.)
$COMF$	=	Combustion factor (dimensionless)
t	=	1, 2, 3, ..., t years elapsed since the project start date
g	=	1, ..., G greenhouse gases (methane and nitrous oxide) (dimensionless)

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

$$B_{WP,t} = N \times \left(\frac{n_{burn,t}}{n_t}\right) \times \left(\frac{1}{n_{t-\Delta t}}\right) \times \sum_{pu=1}^{n_t} B_{WP-woody-AB,pu,t-\Delta t} \tag{19}$$

Where:

$B_{WP,t}$	=	Average aboveground biomass stock subject to burning in the project scenario in the monitoring interval ending in year t (t d.m./ha)
N	=	Initial population size (number of planting units)
n_t	=	Number of planting units sampled in year t (integer)

$n_{burn,t}$	=	Number of sampled planting units recorded as burned in the monitoring interval ending in year t (integer)
$B_{WP\text{-}woody\text{-}AB,pu,t\text{-}\Delta t}$	=	Estimated biomass stock in aboveground woody biomass in sampled planting unit pu in the project scenario in year $t − \Delta t$ (t d.m.)
$n_{t\text{-}\Delta t}$	=	Number of planting units sampled in year $t − \Delta t$ (integer)
t	=	1, 2, 3, …, t years elapsed since the project start date
Δt	=	Length of monitoring interval ending in year t (years)

8.2.2.2 Emissions from Fertilizer Application

Area- and census-based quantification

Where nitrogen fertilizer is applied due to the project activity, nitrous oxide emissions are estimated for area-based and census-based projects as:

$$PE_{fert,t} = PE_{Ndirect,t} + PE_{Nindirect,t} \qquad (20)$$

Where:

$PE_{fert,t}$	=	Project emissions from nitrogen fertilizer in the monitoring period ending in year t (t CO₂e)
$PE_{Ndirect,t}$	=	Direct nitrous oxide emissions due to fertilizer use in the project scenario in the monitoring period ending in year t (t CO₂e)
$PE_{Nindirect,t}$	=	Indirect nitrous oxide emissions due to fertilizer use in the project scenario in monitoring interval ending in year t (t CO₂e)
t	=	1, 2, 3, …, t years elapsed since the project start date

$$PE_{Ndirect,t} = \left(F_{wp,SN,t} + F_{wp,ON,t}\right) \times EF_{Ndirect} \times \frac{44}{28} \times GWP_g \qquad (21)$$

Where:

$PE_{Ndirect,t}$	=	Direct nitrous oxide emissions due to fertilizer use in the project scenario in year t (t CO₂e)
$F_{wp,SN,t}$	=	Synthetic N fertilizer applied in the project scenario in year t (t N)
$F_{wp,ON,t}$	=	Organic N fertilizer applied in the project scenario in the monitoring period ending in year t (t N)
$EF_{Ndirect}$	=	Emission factor for nitrous oxide emissions from N additions due to synthetic fertilizers, organic amendments and crop residues (t N₂O-N/t N applied)
GWP_g	=	Global warming potential for gas g (here, nitrous oxide) (dimensionless)
44/28	=	Ratio of molecular weight of N₂O to molecular weight of N (applied to convert N₂O-N emissions to N₂O emissions) (unitless)
t	=	1, 2, 3, …, t years elapsed since the project start date

25

$$F_{wp,SN,t} = M_{wp,SF,t} \times NC_{wp,SF,t} \tag{22}$$

Where:

$F_{wp,SN,t}$	=	Synthetic N fertilizer applied in the project scenario in the monitoring period ending in year t (t N)
$M_{wp,SF,t}$	=	Mass of N-containing synthetic fertilizer applied in the project scenario in the monitoring interval ending in the monitoring period ending in year t (t fertilizer)
$NC_{wp,SF,t}$	=	N content of synthetic fertilizer applied in the project scenario in the monitoring period ending in year t (t N/t fertilizer)
t	=	1, 2, 3, ..., t years elapsed since the project start date

$$F_{wp,ON,t} = M_{wp,OF,t} \times NC_{wp,OF,t} \tag{23}$$

Where:

$F_{wp,ON,t}$	=	Organic N fertilizer applied in the project scenario in the monitoring period ending in year t (t N)
$M_{wp,OF,t}$	=	Mass of N-containing organic fertilizer applied in the project scenario in the monitoring interval ending in the monitoring period ending in year t (t fertilizer)
$NC_{wp,OF,t}$	=	N content of organic fertilizer applied in the project scenario in the monitoring period ending in year t (t N/t fertilizer)
t	=	1, 2, 3, ..., t years elapsed since the project start date

$$PE_{Nindirect,t} = Nfert_{wp,volat,t} + Nfert_{wp,leach,t} \tag{24}$$

Where:

$PE_{Nindirect,t}$	=	Indirect nitrous oxide emissions due to fertilizer use in the project scenario in monitoring interval ending in year t (t CO_2e)
$Nfert_{wp,volat,t}$	=	Indirect nitrous oxide emissions produced from atmospheric deposition of N volatilized due to nitrogen fertilizer use in the monitoring period ending in year t (t CO_2e)
$Nfert_{wp,leach,t}$	=	Indirect nitrous oxide emissions produced from leaching and runoff of N, in regions where leaching and runoff occurs, due to nitrogen fertilizer use in the monitoring interval ending in year t (t CO_2e)

$$Nfert_{wp,volat,t} = \left[(F_{wp,SN,t} \times Frac_{GASF}) + (F_{wp,ON,t} \times Frac_{GASM}) \right] \times EF_{Nvolat} \times \frac{44}{28} \times GWP_g \qquad (25)$$

Where:

$Nfert_{wp,volat,t}$	=	Indirect nitrous oxide emissions produced from atmospheric deposition of N volatilized due to nitrogen fertilizer use in the monitoring period ending in year t (t CO₂e)
$F_{wp,SN,t}$	=	Synthetic N fertilizer applied in the project scenario in the monitoring period ending in year t (t N)
$Frac_{GASF}$	=	Fraction of all synthetic N added to soils that volatilizes as NH_3 and NO_x (dimensionless)
$F_{wp,ON,t}$	=	Organic N fertilizer applied in the project scenario in the monitoring period ending in year t (t N)
$Frac_{GASM}$	=	Fraction of all organic N added to soils that volatilizes as NH_3 and NO_x (dimensionless)
EF_{Nvolat}	=	Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces (t N_2O-N/(t NH_3-N + NO_x-N volatilized))
GWP_g	=	Global warming potential for gas g (here, nitrous oxide) (dimensionless)
44/28	=	Ratio of molecular weight of N_2O to molecular weight of N (applied to convert N_2O-N emissions to N_2O emissions) (unitless)
t	=	1, 2, 3, …, t years elapsed since the project start date

$$Nfert_{wp,leach,t} = (F_{wp,SN,t} + F_{wp,ON,t}) \times Frac_{LEACH} \times EF_{Nleach} \times \frac{44}{28} \times GWP_g \qquad (26)$$

Where:

$Nfert_{wp,leach,t}$	=	Indirect nitrous oxide emissions produced from leaching and runoff of N, in regions where leaching and runoff occurs, due to nitrogen fertilizer use in the monitoring period ending in year t (t CO₂e)
$F_{wp,SN,t}$	=	Synthetic N fertilizer applied in the project scenario in the monitoring period ending in year t (t N)
$F_{wp,ON,t}$	=	Organic N fertilizer applied in the project scenario in the monitoring period ending in year t (t N)
$Frac_{LEACH}$	=	Fraction of synthetic or organic N added to soils that is lost through leaching and runoff, in regions where leaching and runoff occurs (dimensionless)
EF_{Nleach}	=	Emission factor for nitrous oxide emissions from leaching and runoff (t N_2O-N/t N leached and runoff)
GWP_g	=	Global warming potential for gas g (here, nitrous oxide) (dimensionless)
44/28	=	Ratio of molecular weight of N_2O to molecular weight of N (applied to convert N_2O-N emissions to N_2O emissions) (unitless)
t	=	1, 2, 3, …, t years elapsed since the project start date

8.3 Leakage

Emissions from leakage, LK_t, are accounted using the current version of *VMD0054 Module for Estimating Leakage from ARR Activities*.

Note that for the census-based quantification approach, LK_t is set equal to zero. The requirement that the ARR project activity will not produce continuous vegetative cover (associated with the planting units) on any contiguous area exceeding one hectare (Section 4) avoids any significant displacement of a pre-existing land use and leakage effects are assumed to be de minimis.

8.4 Uncertainty

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

Area-based quantification

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

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

$$UNC_t = MIN \left(100\%, MAX \left(0, \left(\sum_{p=1}^{n} \left(U_{p,t=0} \times C_{p,t=0} \right)^2 + \sum_{p=1}^{n} \left(U_{p,t} \times C_{p,t} \right)^2 \right)^{\frac{1}{2}} \right. \right.$$

$$\left. \left. \times \left(\frac{1}{\Delta C_{WP-biomass,t} + \Delta C_{WP-SOC,t}} \right) - 10\% \right) \right)$$

(27)

Where:

UNC_t	=	Uncertainty in cumulative removals through year *t* (percent)
$U_{p,t}$	=	Percentage uncertainty (expressed as 90 percent confidence interval as a percentage of the mean) in carbon stock estimate of pool p (representing woody biomass, non-woody biomass, dead wood, litter and SOC) in the project scenario in year t (percent)
$C_{p,t}$	=	Carbon stock estimate of pool p (representing woody biomass, non-woody biomass, dead wood, litter and SOC) in the project scenario in year t (t CO_2e)
$\Delta C_{WP-biomass,t}$	=	Change in carbon stock in biomass carbon pools in the project scenario through year *t* (t C)
$\Delta C_{WP-SOC,t}$	=	Change in carbon stock in SOC in the project scenario through year *t* (t C)

t	=	1, 2, 3, …, t years elapsed since the project start date

Census-based quantification

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

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

$$UNC_t = MIN\left(100\%, MAX\left(0, \left(U_{p,t}{}^2 + U_{M,t}^2\right)^{\frac{1}{2}} - 10\%\right)\right) \tag{28}$$

Where:

UNC_t	=	Uncertainty in cumulative removals through year t (percent)
$U_{p,t}$	=	Percentage uncertainty (expressed as 90 percent confidence interval as a percentage of the mean) in pool p (here restricted to woody biomass $C_{WP\text{-}biomass}$) in the project scenario in year t (percent)
$U_{M,t}$	=	Percentage uncertainty in population size adjusted for mortality in the project scenario in year t (percent)
t	=	1, 2, 3, …, t years elapsed since the project start date

$$U_{M,t} = T \times \left(\frac{M_t \times (1 - M_t)}{n_t - 1}\right)^{\frac{1}{2}} \times \left(\frac{1}{1 - M_t}\right) \tag{29}$$

Where:

$U_{M,t}$	=	Percentage uncertainty in population size adjusted for mortality in the project scenario in year t (percent)
T	=	Critical value of a student's t-distribution for significance level α = 0.1
M_t	=	Mortality through year t (percent)
n_t	=	Number of planting units sampled in year t (integer)
t	=	1, 2, 3, …, t years elapsed since the project start date

For both census- and area-based quantification approaches, a project is not eligible for crediting (CR_t = 0) where the half-width of the two-sided 90 percent confidence interval exceeds 100 percent of the carbon dioxide removal estimate.

8.5 Estimated Carbon Dioxide Removals

For monitoring intervals longer than one year, carbon removals are calculated by comparing the carbon stock at the current monitoring year (t) to the carbon stock at t minus the length of the monitoring interval (e.g., t-5 for a 5-year interval). The total removals for the period are then divided by the number of years in the monitoring interval (Eq. 32) to calculate an annualized value, ensuring equal carbon removals (CRt) are assigned to each year within the interval.

Area-based quantification

$$
\begin{aligned}
CR_t &= \left(\left(\Delta C_{WP,t} \times (1 - PB_t) \times (1 - UNC_t)\right) - LK_t\right) - PE_t \\
&\quad - \left(\left(\Delta C_{WP,t-1} \times (1 - PB_{t-1}) \times (1 - UNC_{t-1})\right) - PE_{t-1} - LK_{t-1}\right) CR_t \\
&= \left(\text{MIN}\left(\Delta C_{WP,t}, \Delta C_{WP,t} \times (1 - PB_t)\right) \times (1 - UNC_t)\right) - PE_t - LK_t \\
&\quad - \left(\left(\text{MIN}\left(\Delta C_{WP,t-x}, \Delta C_{WP,t-x} \times (1 - PB_{t-x})\right) \times (1 - UNC_{t-x})\right) \right. \\
&\quad \left. - PE_{t-x} - LK_{t-x}\right)
\end{aligned}
\tag{30}
$$

Where:

CR_t	=	Carbon dioxide removals from the project activity in the monitoring interval ending in year t (t CO₂e)
$\Delta C_{WP,t}$	=	Project carbon stock change in year t (t CO₂e)
PB_t	=	Performance benchmark for the monitoring interval ending in year t (percent)
LK_t	=	Leakage through year t (t CO₂e)
PE_t	=	Project emissions from biomass burning and fertilizer use in the monitoring interval ending in year t (t CO₂e)
UNC_t	=	Uncertainty in cumulative removals through year t (percent)
x	=	Length of the monitoring period

Census-based quantification

Carbon dioxide removals using census-based quantification are calculated with carbon stock changes in the baseline scenario (see Section 6) and leakage (see Section 8.3) implicitly set equal to zero.

$$
\begin{aligned}
CR_t &= (\Delta C_{WP,t} \times (1 - UNC_t)) - (\Delta C_{WP,t-1} \times (1 - UNC_{t-1})) - PE_t CR_t \\
&= \left(((\Delta C_{WP,t} \times (1 - UNC_t)) - (\Delta C_{WP,t-1} \times (1 - UNC_{t-1}))) - PE_t\right)
\end{aligned}
\tag{31}
$$

Where:

CR_t	=	Carbon dioxide removals from the project activity *in* the monitoring interval (t CO₂e/yr)
$\Delta C_{WP,t}$	=	Project carbon stock change through year t (t CO₂e)

PE_t	=	*Project emissions from biomass burning and fertilizer in year t (t CO₂e)*
t	=	*1, 2, 3, …, t years elapsed since the project start date*

Where the project combines area- and census-based quantification approaches, total removals are calculated as the sum of the removals calculated independently for each approach (applied to non-overlapping areas).

Where the project activity includes harvesting, the project must also follow guidance in the current version of the *VCS Standard* for applying the long-term average GHG benefit as an upper limit on calculated carbon dioxide removals.

8.5.1 Annualized Carbon Removals

To calculate annualized carbon removals (CRAnnualized) divide the total carbon removals (CRt) in the monitoring interval by the length of the monitoring interval (x):

$$CR_{annualized} = \frac{CR_t}{x} \tag{32}$$

CRannualized	=	Annualized carbon removals per year
CRt	=	Carbon dioxide removals from the project activity over the monitoring interval (t CO2e/yr)
x	=	Length of the monitoring period in years,

8.6 Ex-Ante Estimation

The project description must include an ex-ante estimation of carbon dioxide removals that meets the following requirements:

- At the time *t* of validation, estimates must be made for the 10-year period from time *t* to *t+10*

- At the time *t* of every verification, estimates may be updated for the 10-year period from time *t* to *t+10* (i.e., every verification may be accompanied by an ex-ante estimate projecting 10 years into the future)

- Projected changes in biomass must be based on growth and yield models constructed with data and parameters that conservatively represent the project activity

- Any harvest regimes or forest management activities planned for the 10-year period over which the ex-ante calculations are projected must be incorporated in modelling the project scenario

- A minimum uncertainty deduction of 10 percent must be applied. An uncertainty deduction greater than 10 percent may be selected by the project proponent if they wish to be more conservative

- The ex-ante estimate of removals is derived by executing Equations ([1]) and (2) with parameters estimated as follows: $\Delta C_{WP-biomass,t}$: Modelled growth and yield values. The output of the growth and yield model must provide an estimate in value of tC, which provides the value for $\Delta C_{WP-biomass,t}$ used in Equation (2).

- ΔSI_{wp} : Modelled from relationship with growth and yield values (i.e., regression). The growth and yield projection will also be used to derive an estimate of stocking index value ΔSI_{wp}. This is done by using a regression model from a published study or validation dataset that establishes the relationship between tC in biomass and stocking index, ΔSI_{wp}.

- $\Delta SI_{control}$: Modelled based on performance between t and t-10 assuming a linear relationship (e.g., if $\Delta SI_{control}$ increased by 10% over the past ten years, the same increase would be assumed over the next ten years).

- All other carbon pools (i.e., soil organic carbon) and GHG emission sources can be assumed to be zero unless it is not conservative to do so.

9 MONITORING

9.1 Data and Parameters Available at Validation

Data/Parameter	A
Data unit	ha
Description	Project area
Equations	(3), (8), (10), (12), (14)
Source of data	Calculated from GIS data
Value applied	Project-specific
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 with GPS, 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	Calculation of project emissions using the area-based quantification approach

Comments	The project activity may contain more than one discrete area of land. Each discrete area of land must have a unique geographic identification.

Data/Parameter	R
Data unit	dimensionless
Description	Root to shoot ratio (i.e., ratio of belowground (root) biomass to aboveground biomass, per unit area or per stem)
Equations	(4) (7)
Source of data	The source of data must be chosen as follows:
	For project activities involving facilitated natural regeneration or with more than two species in a single stand, *R* must be chosen from the following as available, listed in descending order of preference:
	a) Values specific to the forest type within the same ecoregion (defined at the biome level[7]) or Holdridge life-zone[8] as the region in which the project is located; or
	b) Global values specific to the forest type (e.g., from Table 4.4 in Chapter 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*).
	Otherwise (e.g., in the case of monoculture plantations), *R* must be chosen from the following as available, listed in descending order of preference:
	c) Values specific to the species, genus or family within the same ecoregion or Holdridge life-zone as the region in which the project is located; or
	d) Global values specific to the species, genus or family (e.g., from Table 4.4 in Chapter 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*).
	Note that where a global *R* ratio is used, it must have been developed from or validated with datasets including direct measurements collected via destructive sampling from within the same ecoregion or Holdridge life-zone as the region in which the project is located.
Value applied	Project-specific
Justification of choice of data or description of measurement methods and procedures applied	See "Source of data"
Purpose of data	Calculation of project emissions using the area-based and census-based quantification approaches
Comments	None

---

[7] https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world?https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world

[8] http://iridl.ldeo.columbia.edu/SOURCES/.ECOSYSTEMS/.Holdridge/present+.life-zone/downloadsGeoTiff.html

Data/Parameter	CF
Data unit	t C/t d.m.
Description	Carbon fraction of dry biomass
Equations	(7), (9), (11), (13), (17)
Source of data	IPCC 2006 Guidelines for National Greenhouse Gas Inventories
Value applied	0.47
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS
Purpose of data	Calculation of project emissions using the area-based and census-based quantification approaches
Comments	None

Data/Parameter	N
Data unit	Integer
Description	Initial population size (number of planting units)
Equations	(6), (19)
Source of data	Complete census/enumeration
Value applied	The original population size, N, is established via administering and recording an initial complete census of all planting units. For each planting unit, the following must be recorded: • Unique ID • Geo-referenced point of the location • Year planted • Species
Justification of choice of data or description of measurement methods and procedures applied	See "Source of data"
Purpose of data	Calculation of project emissions using the census-based quantification approach
Comments	Planting units must be clearly defined (e.g., tree, shrub, bamboo clump) and identifiable in the field.

Data/Parameter	$EF_{Ndirect}$

Data unit	t N_2O-N/t N applied
Description	Emission factor for direct nitrous oxide emissions from N additions due to synthetic fertilizers, organic amendments and crop residues
Equations	(21)
Source of data	Table 11.1, Chapter 11 in Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Value applied	0.01
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
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 N added to soils that volatilizes as NH3 and NOx
Equations	(25)
Source of data	Table 11.3, Chapter 11 in Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Value applied	0.11
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Comments	None

Data/Parameter	$Frac_{GASM}$
Data unit	Dimensionless
Description	Fraction of all organic N added to soils that volatilizes as NH_3 and NO_x
Equations	(25)
Source of data	Table 11.3, Chapter 11 in Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*

35

Value applied	0.21
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Comments	None

Data/Parameter	EF_{Nvolat}
Data unit	t N_2O-N/(t NH_3-N + NO_x-N volatilized)
Description	Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces
Equations	(25)
Source of data	Table 11.3, Chapter 11 in Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Value applied	0.01
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Comments	None

Data/Parameter	$Frac_{LEACH}$
Data unit	Dimensionless
Description	Fraction of synthetic or organic N added to soils that is lost through leaching and runoff
Equations	(26)(**21**)
Source of data	Table 11.3, Chapter 11 in Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Value applied	0.24
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS.
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches

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	(26)
Source of data	Table 11.3, Chapter 11 in Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Value applied	0.011
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Comments	None

Data/Parameter	*COMF*
Data unit	Dimensionless
Description	Combustion factor
Equations	(16), (18)
Source of data	Default mean values in Table 2.6 of IPCC *2019 Refinement to the 2006 Guidelines for National Greenhouse Gas Inventories*
Value applied	The combustion factor is selected based on vegetation type. For the census-based approach, a conservative value of 1.0 is applied.
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Comments	None

Data/Parameter	EF_g
Data unit	kg/t d.m. burned
Description	Emission factor for gas *g*

Equations	(16), (18)
Source of data	Table 2.5, Chapter 2, Volume 4 of the *IPCC 2006 Guidelines for National Greenhouse Gas Inventories* (see Appendix 2: Emission factors for various types of burning for CH_4 and N_2O)
Value applied	Project-specific
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Comments	None

Data/Parameter	GWP_g
Data unit	Dimensionless
Description	Global warming potential for gas g
Equations	(16), (18), (21) (25), (26)
Source of data	Default factor from the latest IPCC Assessment Report
Value applied	Most recent IPCC Assessment Report
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Comments	None

9.2   Data and Parameters Monitored

Data/Parameter	M_t
Data unit	Percent
Description	Mortality through year t
Equations	(6), (29)
Source of data	Complete re-enumeration, or sampling
Description of measurement methods and procedures to be applied	If sampling, planting units must be representatively sampled from the census list on which parameter N is based, compiled prior to sampling. Stratification (e.g., sub-dividing the census list into annual cohorts) may be employed to improve precision but is not required. An appropriate representative sample would be a stratified systematic sample, within

	each annual cohort, selecting planting units systematically with a random start from the list of unique censused planting units.
	Planting units are assessed as dead where:
	1) Green vascular tissue (e.g., cambium of trees and shrubs) and green leaves are absent, or
	2) It is not possible to relocate the planting unit.
Frequency of monitoring/recording	Every 5 years or more frequently. Sampling for incidence of mortality may be conducted simultaneously with sampling planting units for biomass measurement.
QA/QC procedures to be applied	See "Description of measurement methods and procedures to be applied"
Purpose of data	Calculation of project emissions using the census-based quantification approach
Calculation method	Calculated as a percentage of a sample or census
Comments	None

Data/Parameter	$C_{WP\text{-}woody\text{-}AB,t}$
Data unit	t C/ha
Description	Average aboveground woody biomass stocks in the project scenario in year t (area-based quantification)
Equations	(4)
Source of data	Field measurement
Description of measurement methods and procedures to be applied	Aboveground woody biomass must be measured via plot-based sampling.
	Stratification may be employed to improve precision but is not required. Sample design need not be held constant across all monitoring and verification events.
	Plot-based sampling approaches (using area-based quantification) may be augmented using double or two-phase sampling approaches (e.g., 3P or ratio sampling). These approaches must include:
	1) A complete census of an auxiliary variable (e.g., stocking index, see Appendix 1), and
	2) A sample of direct field-based measurements used to determine the relationship (i.e., a ratio or regression) between aboveground woody biomass and the auxiliary variable.
	All sample measurements must:
	a) Be demonstrated to be unbiased and derived from representative sampling;
	b) Ensure accuracy through adherence to best practices and quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection); and
	c) Apply fixed size thresholds on independent variables used in biomass estimation (e.g., diameter at breast height, diameter at root collar, height), to be maintained through the crediting period.

	Aboveground woody biomass of each sampled woody plant (e.g., tree, shrub) is estimated using published allometric equations applied to one or more measured attributes.
	For project activities involving facilitated natural regeneration or with more than two species in a single stand, equation(s) must be chosen from the following as available, listed in descending order of preference:
	i) Equations specific to the forest type within the same ecoregion (defined at the biome level[9]) or Holdridge life-zone[10] as the region in which the project is located, or
	ii) Global equations specific to the forest type.
	Otherwise (e.g., in the case of monoculture plantations), equation(s) must be chosen from the following as available, listed in descending order of preference:
	iii) Equations specific to the species, genus or family within the same ecoregion or Holdridge life-zone as the region in which the project is located, or
	iv) Global equations specific to the species, genus or family.
	Note that where global allometric equations are used, equations must have been developed from or validated with datasets including direct measurements collected via destructive sampling from within the same ecoregion or Holdridge life-zone as that in which the project is located.
	Attributes (e.g., diameter at breast height, 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., Ducey, M. J., Beers, T. W., & Husch, B. (2016). *Forest mensuration*. John Wiley & Sons.
	Avery, T. E., & Burkhart, H. E. (2015). *Forest measurements*. Waveland Press.
	Measurement protocols must be detailed in standard operating procedures. Parameter tables for all attributes (e.g., diameter at breast height, total height) incorporated as independent variables in allometric equations must be included in the project description under "Data and Parameters Monitored."
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	To be determined by the project proponent and outlined in standard operating procedures governing field data collection
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	Tool *VT0005* does not apply.

Data/Parameter	$B_{WP\text{-}woody\text{-}AB,pu,t}$
Data unit	t d.m.

---

[9] https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world?https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world

[10] http://iridl.ldeo.columbia.edu/SOURCES/.ECOSYSTEMS/.Holdridge/present+.life-zone/downloadsGeoTiff.html

Description	Estimated biomass stock in aboveground woody biomass in sampled planting unit *pu* in the project scenario in year *t* (census-based quantification)
Equations	(7), (19)
Source of data	Field measurement
Description of measurement methods and procedures to be applied	Aboveground woody biomass is measured via representative sampling from *N* planting units.

Stratification (e.g., sub-dividing the census list into annual cohorts) may be employed to improve precision but is not required. An appropriate representative sample would be a stratified systematic sample within each annual cohort, selecting planting units systematically with a random start from the list of unique censused planting units. Sample design need not be held constant across all monitoring and verification events.

All sample measurements must:

1) Be demonstrated to be unbiased and derived from representative sampling;

2) Ensure accuracy through adherence to best practices and quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection); and

3) Apply fixed size thresholds on independent variables used in biomass estimation (e.g., diameter at breast height, diameter at root collar, height), to be maintained through the crediting period.

Aboveground woody biomass of each sampled woody plant (e.g., tree, shrub) is estimated using published allometric equations applied to one or more measured attributes.

Equation(s) must be chosen from the following as available, listed in descending order of preference:

a) Equations specific to the species, genus or family within the same ecoregion or Holdridge life-zone as the region in which the project is located, or

b) Global equations specific to the species, genus or family.

Note where global allometric equations are used, equations must have been developed from, or validated with, datasets including direct measurements collected via destructive sampling from within the same ecoregion or Holdridge life-zone as that in which the project is located.

Attributes (e.g., diameter at breast height, 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., Ducey, M. J., Beers, T. W., & Husch, B. (2016). *Forest mensuration*. John Wiley & Sons.

Avery, T. E., & Burkhart, H. E. (2015). *Forest measurements*. Waveland Press.

Measurement protocols must be detailed in standard operating procedures. Parameter tables for all attributes (e.g., diameter at breast height, total height) incorporated as independent variables in allometric equations must be included in the project description under "Data and Parameters Monitored."

Frequency of monitoring/recording	Every five years or more frequently

41

QA/QC procedures to be applied	To be determined by the project proponent and outlined in standard operating procedures governing field data collection
Purpose of data	Calculation of project emissions using the census-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	Note that where a sampled live planting unit is less than the pre-determined size (e.g., minimum diameter at breast height) threshold, it is assigned a value of zero and included in the sample dataset.

Data/Parameter	$DM_{WP\text{-}herb,t}$
Data unit	t d.m./ha
Description	Average non-woody biomass in the project scenario in year t
Equations	(9)
Source of data	Field measurements
Description of measurement methods and procedures to be applied	Non-woody biomass is measured via plot-based sampling. Stratification may be employed to improve precision but is not required. Sample design need not be held constant across all monitoring and verification events. Sample measurements must: 1) Be demonstrated to be unbiased and derived from representative sampling; and 2) Ensure accuracy through adherence to best practices and quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection). Aboveground non-woody biomass (herb) is defined as a pool that includes both living and dead non-woody plant mass. All living and dead non-woody biomass is clipped above the soil surface from inside each sample frame. Dry mass is determined either by drying the entire wet sample to a constant weight or by drying a subsample of the wet mass to determine a dry-to-wet mass ratio conversion factor. Because aboveground mass may be highly seasonal, the average pool must be calculated from at least two samples representing the minimum and maximum standing stocks. Alternatively, a conservative estimate of the pool may be determined from a sample taken at the time of minimum standing stock.
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	Note that where subsampling is employed to determine a dry-to-wet mass ratio, uncertainty is calculated by treating the sample as a double sample (see parameter $U_{p,t}$).

Data/Parameter	$n_{burn,t}$

Data unit	Integer
Description	Number of sampled planting units recorded as burned in the monitoring interval ending in year t
Equations	(19)
Source of data	Field sampling
Description of measurement methods and procedures to be applied	With census-based quantification, measured via representative sampling from N planting units, tallying each visibly burned and killed planting unit. Measurement protocols must be detailed in standard operating procedures.
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	See "Description of measurement methods and procedures to be applied"
Purpose of data	Calculation of project emissions using the census-based quantification approach
Calculation method	Count (not calculated)
Comments	None

Data/Parameter	$U_{p,t}$
Data unit	Percent
Description	Percentage uncertainty (expressed as 90 percent confidence interval as a percentage of the mean) in carbon stock estimate of pool p in the project scenario in year t
Equations	(27), (30)
Source of data	Calculations from sampled field measurements
Description of measurement methods and procedures to be applied	Uncertainty in pools derived from field measurements with 90 percent confidence interval calculated as the standard error of the averaged plot measurement multiplied by the t value for the 90 percent confidence level Where double or two-phase sampling approaches are employed for aboveground woody biomass, parameter $U_{p=woody,t}$ is represented by error in the relationship (ratio or regression) between the auxiliary variable and woody biomass, referencing the 90 percent confidence interval of the ratio or 1.645 times the root mean squared error of the regression. Sample error in the auxiliary variable is not treated, because it must be subject to a complete census (see parameter table for $C_{WP\text{-}woody\text{-}AB,t}$ above). Where double or two-phase sampling approaches are employed for non-woody biomass and/or litter (i.e., where subsampling is employed to estimate the dry-to-green weight ratio that is then applied to a sample estimate of green weight (see parameter tables for $DM_{WP\text{-}herb,t}$ and $DM_{WP\text{-}Ll,t}$), parameters $U_{p=non\text{-}woody,t}$ and $U_{p=litter,t}$ are calculated by propagating sample error of the green weight estimate and sample error of the estimate of dry-to-green weight ratio.
Frequency of monitoring/recording	Every five years or more frequently

QA/QC procedures to be applied	See "Description of measurement methods and procedures to be applied"
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Calculation method	Confidence interval calculated by applying unbiased estimators appropriate to sample design. For examples, see Cochran, W.G. (1977). *Sampling techniques*. John Wiley & Sons.
Comments	For the area-based quantification approach, pools p include woody biomass, non-woody biomass, dead wood, litter and SOC. For the census-based quantification approach, pools p include woody biomass only.

Data/Parameter	$A_{burn,t}$
Data unit	ha
Description	Area burned in the monitoring interval ending in year t
Equations	(16)
Source of data	Calculated from GIS data
Description of measurement methods and procedures to be applied	Delineation of the area burned may use a combination of remote imagery (satellite or aerial photographs) or ground survey data with GPS.
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	Any imagery used must be geo-registered referencing corner points, clear landmarks or other intersection points.
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated using GIS
Comments	None

Data/Parameter	$M_{wp,SF,t}$
Data unit	t fertilizer
Description	Mass of N-containing synthetic fertilizer applied in the project scenario in the monitoring interval ending in year t
Equations	(22)
Source of data	Mass of synthetic fertilizer applied in the project, as recorded in land management records
Description of measurement methods and procedures to be applied	Information is monitored via direct consultation with, and substantiated with a written attestation from, the local land manager.

Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Any quantitative information (e.g., discrete or continuous numeric variables) on management practices must be supported by one or more forms of documented evidence pertaining to the project and relevant monitoring period (e.g., management logs, receipts or invoices).
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Calculation method	Not calculated
Comments	None

Data/Parameter	$M_{wp,OF,t}$
Data unit	t fertilizer
Description	Mass of N-containing organic fertilizer applied in the project scenario in the monitoring interval ending in year t
Equations	(23)
Source of data	Mass of organic synthetic fertilizer applied in the project, as recorded in land management records.
Description of measurement methods and procedures to be applied	Information is monitored via direct consultation with, and substantiated with a written attestation from, a local land manager.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Any quantitative information (e.g., discrete or continuous numeric variables) on management practices must be supported by one or more forms of documented evidence pertaining to the project and relevant monitoring period (e.g., management logs, receipts or invoices).
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches.
Calculation method	Not calculated
Comments	None

Data/Parameter	$NC_{wp,SF,t}$
Data unit	t N/t fertilizer
Description	N content of synthetic fertilizer applied in the project in year t
Equations	(22)(**21**)
Source of data	N content is determined following fertilizer manufacturer's specifications.
Description of measurement methods	Not directly measured. Recorded from fertilizer manufacturer's specifications and evidenced in management records, receipts or invoices.

and procedures to be applied	
Frequency of monitoring/recording	Monitoring must be conducted at least every five years or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Any quantitative information on management practices must be supported by one or more forms of documented evidence pertaining to the project area and relevant monitoring period (e.g., management logs, receipts or invoices).
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Calculation method	Not calculated
Comments	None

Data/Parameter	$NC_{wp,OF,t}$
Data unit	t N/t fertilizer
Description	N content of organic fertilizer applied in the project in year t
Equations	(23)
Source of data	Published or peer-reviewed data must be used, with preference for more recent data from the project country.
Description of measurement methods and procedures to be applied	Not directly measured
Frequency of monitoring/recording	Monitoring must be conducted at least every five years or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Data referenced must be published or peer-reviewed.
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Calculation method	Not calculated
Comments	None

Data/Parameter	$B_{SDW,t}$
Data unit	t d.m./ha
Description	Average biomass of standing dead wood in year t
Equations	(11)
Source of data	Field measurements
Description of measurement methods and procedures to be applied	Standing dead wood is measured via plot-based sampling. Stratification may be employed to improve precision but is not required. Sample design need not be held constant across all monitoring and verification events.

Sample measurements must:

1) Be demonstrated to be unbiased and derived from representative sampling;

2) Ensure accuracy through adherence to best practices and quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection); and

3) Apply fixed size thresholds.

For each standing dead woody plant (e.g., tree, shrub), stem volume must be estimated using published allometric equations applied to one or more measured attributes.

For project activities involving facilitated natural regeneration or with more than two species in a single stand, equation(s) must be chosen from the following as available, listed in descending order of preference:

a) Equations specific to the forest type within the same ecoregion (defined at the biome level[11]) or Holdridge life-zone[12] as the region in which the project is located, or

b) Global equations specific to the forest type.

Otherwise (e.g., in the case of monoculture plantations), equation(s) must be chosen from the following as available, listed in descending order of preference:

c) Equations specific to the species, genus or family within the same ecoregion or Holdridge life-zone as the region in which the project is located, or

d) Global equations specific to the species, genus or family.

Note that where global allometric equations are used, equations must have been developed from or validated with datasets including direct measurements collected via destructive sampling from within the same ecoregion or Holdridge life-zone as the region in which the project is located.

Note that standing dead wood is restricted here to visible aboveground stem (bole) biomass, and must discount any missing portions of the stem (e.g., referencing visible break height in volume estimation).

Attributes (e.g., diameter at breast height, 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., Ducey, M. J., Beers, T. W., & Husch, B. (2016). *Forest mensuration*. John Wiley & Sons.

Avery, T. E., & Burkhart, H. E. (2015). *Forest measurements*. Waveland Press.

Measurement protocols must be detailed in standard operating procedures. Parameter tables for all attributes (e.g., diameter at breast height, total height) incorporated as independent variables in allometric equations must be included in the project description under "Data and Parameters Monitored."

Biomass of standing dead wood must be estimated from sampled volumes using published wood densities (specific to the species, genus, family or forest type as available, in descending order of preference) and

---

[11] https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world?https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world

[12] http://iridl.ldeo.columbia.edu/SOURCES/.ECOSYSTEMS/.Holdridge/present+.life-zone/downloadsGeoTiff.html

	density reduction factors referencing decomposition states (e.g., procedures per Harmon et al., 2011).
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	See "Description of measurement methods and procedures to be applied"
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	None

Data/Parameter	$B_{LDW,t}$
Data unit	t d.m./ha
Description	Average biomass of lying dead wood in year t
Equations	(11)
Source of data	Field measurements
Description of measurement methods and procedures to be applied	Lying dead wood is sampled via line intersect sampling (Van Wagner, 1968; Warren and Olsen, 1964), perpendicular distance sampling (Ducey et al., 2013; Williams and Gove, 2003; Williams et al., 2005) or other un-biased approaches. Stratification may be employed to improve precision but is not required. Sample design need not be held constant across all monitoring and verification events. Sample measurements must: 1) Be demonstrated to be unbiased and derived from representative sampling; 2) Ensure accuracy through adherence to best practices and quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection); and 3) Apply fixed size thresholds. Protocols must be detailed in standard operating procedures and parameter tables under "Data and Parameters Monitored" for all lying dead wood attributes (e.g., cross-sectional diameter, length) measured and recorded. Biomass of lying dead wood must be estimated from sampled volumes using published wood densities (specific to species, genus, family or forest type, in descending order of preference) and density reduction factors referencing decomposition states (e.g., procedures per Harmon et al., 2011).
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	See "Description of measurement methods and procedures to be applied"
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated as the average of sample measurements

Comments	None

Data/Parameter	$DM_{WP\text{-}LI,t}$
Data unit	t d.m./ha
Description	Average litter dry mass per hectare in the project scenario in year t
Equations	(13)
Source of data	Field measurements
Description of measurement methods and procedures to be applied	Litter is measured via destructive sampling. Stratification may be employed to improve precision but is not required. Sample design need not be held constant across all monitoring and verification events. Litter (dead organic surface material of less than 10 cm diameter) is collected from within fixed-area sampling frames, harvested at ground level and dried at 70 °C to a constant weight to determine dry weight biomass. In cases where sample bulk is excessive, the green weight of the total sample and of a representative sub-sample are recorded in the field and the sub-sample taken for moisture content determination in the lab (i.e., oven dry weight to green weight ratio), from which the dry weight biomass of the total green weight recorded in the field is estimated. Further guidance is provided in the IPCC (2003) *Good Practice Guidance for Land-Use, Land-Use Change and Forestry (GPG-LULUCF)*.
Frequency of monitoring/recording	At t = 0 and subsequently every five years or more frequently
QA/QC procedures to be applied	Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QC procedures available from published hand-books, such as those published by FAO and available on the FAO Soils Portal[13] or from the IPCC (2003) *GPG LULUCF* is recommended.
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	Note that where subsampling is employed to determine a dry-to-green weight ratio, uncertainty is calculated by treating the sample as a double sample (see parameter $U_{p,t}$).

Data/Parameter	$C_{WP\text{-}SOC,t}$
Data unit	t C/ha
Description	Average soil organic carbon (SOC) stock in year t
Equations	(14)
Source of data	Field measurements
Description of measurement methods	Measured SOC must be determined from samples collected from sample plots located within the project area. Stratification may be employed to

---

[13] http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/

and procedures to be applied	improve precision but is not required. Sample design need not be held constant across all monitoring and verification events.
	All organic material (e.g., living plants, litter) must be cleared from the soil surface prior to soil sampling. Soil must be sampled to a minimum depth of 30 cm. SOC stocks must be estimated from measurements of both SOC content and bulk density taken at the same time.
	Estimates generated must:
	1) Be demonstrated to be unbiased and derived from representative sampling; and
	2) Ensure accuracy through employment of quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in the monitoring plan).
	Soil sampling must follow established best practices, such as those found in:
	Cline, M. G. (1944). Principles of soil sampling. *Soil Science*, *58*(4), 275–288.
	Petersen, R. G., & Calvin, L. D. (1986). Sampling. In A. Klute (Ed.), *Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods*. Soil Science Society of America and American Society of Agronomy.
	Re-measurement of soil carbon (after t = 0) must use equivalent soil mass procedures (see Wendt & Hauser, 2013).
	Determination of percent SOC must follow established laboratory procedures, such as those found in:
	Nelson, D. W., & Sommers, L. E. (1996). Total carbon, organic carbon, and organic matter. In A. L. Page et al. (Eds.) *Methods of Soil Analysis. Part 3 Chemical methods*. American Society of Agronomy and Soil Science Society of America.
	Schumacher, B. A. (2002). *Methods for the determination of total organic carbon (TOC) in soils and sediments*. U.S. Environmental Protection Agency, EPA/600/R-02/069 (NTIS PB2003-100822), or other regionally appropriate sources such as the European Environment Agency.
	Procedures for SOC and bulk density (including all sample handling, preparation for analysis and analysis techniques) must be thoroughly described in field sampling protocols and in parameter tables under "Data and Parameters Monitored."
Frequency of monitoring/recording	At time t = 0 and subsequently at every verification (every five years or more frequently).
	SOC may be measured less frequently than other pools (but not less frequently than every 10 years) and reported as zero during intervening monitoring and verification events where soil disturbance from the project activity (i.e., from site preparation):
	a) Occurs no more than once during the project crediting period (i.e., at site preparation); or
	b) Does not involve soil inversion to a depth exceeding 25 cm (e.g., that would result from a moldboard plow).
QA/QC procedures to be applied	Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QC procedures available from published hand-books, such as those

	published by FAO and available on the FAO Soils Portal[14] or from the IPCC (2003) *GPG LULUCF* is recommended.
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	None

9.3 Description of the Monitoring Plan

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

1) Specification of the quantification approach applied (area-based or census-based). Where using the census-based approach, clearly define the planting unit. If using area-based approach, see procedures below in Section 9.3.1;

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

3) Definition of the accounting boundary. Where area-based and census-based quantification approaches are used in the same project, the monitoring plan must specify the spatial accounting boundary for the area-based approach, and demonstrate non-overlap with the census-based approach (applying area specifications detailed in Section 5);

4) Parameters to be measured, including parameter tables for all directly measured woody plant 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, including data used in monitoring of the performance benchmark, documented in a standard operating procedure for field data collection. Sample designs must be specified (clearly delineate the sample population, justify sampling intensities, selection of sample units and sampling stages, where applicable) and un-biased estimators of population parameters identified that are applied in calculations;

6) Anticipated frequency of monitoring for each variable;

7) Quality assurance and quality control (QA/QC) procedures to ensure accurate data collection and to screen for, and where necessary, correct anomalous values, ensure

---

[14] http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/

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 of the monitoring team and management. Roles and responsibilities defined for chain of custody, repositing and maintenance of all data;

10) The monitoring plan must also specify the schedule and procedures for periodically acquiring, archiving, and processing remote sensing data to derive stocking indices; and

11) A full description of the stocking index, and the process to derive it (reference to the database is insufficient).

9.3.1 Database Requirements for Project and Control Plots

For projects using the area-based quantification approach, a database must be maintained where datasets related to plots are reposited. The database must include, at a minimum:

1) A description of the stocking index and the process to derive it;

2) A list of project plots including unique IDs, locations, size and configuration and time series of stocking index values from time t = 0 to time t.

3) A list of control plots including unique IDs (referencing unique ID of corresponding project plot to which they are matched), locations, size and configuration, weights and time series of stocking index values from time t = 0 to time t; and

4) Remote sensing datasets and time stamps used to derive stocking index values.

10 REFERENCES

Avery, T. E., & Burkhart, H.E. (2015). *Forest measurements*. Waveland Press.

Bird, D.N, Pena, N., Schwaiger, H., & Zanchi, G. (2010). Review of existing methods for carbon accounting. CIFOR, Occasional Paper (54).

Cline, M. G. (1944). Principles of soil sampling. S*oil Science, 58*(4), 275–288.

Cochran, W.G. (1977). *Sampling technique*s. John Wiley & Sons.

Ducey, M. J., Williams, M. S., Gove, J. H., Roberge, S., & Kenning, R. S. (2013). Distance-limited perpendicular distance sampling for coarse woody debris: Theory and field results. *Forestry, 86*(1), 119–128.

Ferraro, P. J., & Hanauer, M.M. (2014). Advances in measuring the environmental and social impacts of environmental programs. *Annual Review of Environment and Resources,* 39, 495–517.

Harmon, M. E., Woodall, C. W., Fasth, B., Sexton, J., & Yatkov, M. (2011). Differences between standing and downed dead tree wood density reduction factors: A comparison across decay classes and tree species. Research Paper NRS-15. US Department of Agriculture, Forest Service.

Holdridge, L. R. (1967). *Life zone ecology*. Tropical Science Center.

IPCC (2003). *Good practice guidance for land use, land-use change and forestry*. Institute for Global Environmental Strategies (IGES). https://www.ipcc.ch/publication/good-practice-guidance-for-land-use-land-use-change-and-forestry/

IPCC (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Institute for Global Environmental Strategies (IGES).

IPCC (2019). *Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4. IPCC. https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

Kershaw Jr, J. A., Ducey, M. J., Beers, T. W., & Husch. (2016). *Forest mensuration*. John Wiley & Sons.

Mathur, A., Chikkatur, A. P., & Sagar, A.D. (2007). Past as prologue: An innovation-diffusion approach to additionality. *Climate Policy*, *7*(3):, 230–239.

Nelson, D. W., & Sommers, L. E. (1996). Total carbon, organic carbon, and organic matter. In A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C T. Johnston, M. E. Sumner (Eds.) *Methods of soil analysis. Part 3 Chemical methods*. American Society of Agronomy and Soil Science Society of America. (pp. 961–1010).

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C.J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., & Kassem, K. R. (2001). Terrestrial Ecoregions of the World: A New Map of Life on Earth. A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *BioScience*, *51*(11),933–938.

Petersen, R. G., & Calvin, L.D. (1986). Sampling. In A. Klute (Ed.), *Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods*. American Society of Agronomy and Soil Science Society of America.

Schumacher, B. A. (2002.). *Methods for the determination of total organic carbon (TOC) in soils and sediments*. U.S. Environmental Protection Agency.

Souza Jr, C. M., Roberts, D. A., & Cochrane, M.A., (2005). Combining spectral and spatial information to map canopy damage from selective logging and forest fires. *Remote Sensing of Environment, 98*(2–3), 329–343.

Van Wagner, C.E. (1968). The line intersect method in forest fuel sampling. *Forest Science, 14*(1), 20–26.

Warren, W. G., & Olsen, P.F. (1964). A line intersect technique for assessing logging waste. *Forest Science 10*(3), 267–276.

Wendt, J. W., & Hauser, S. (2013). An equivalent soil mass procedure for monitoring soil organic carbon in multiple soil layers. *European Journal of Soil Science, 64*(1), 58–65.

Williams, M. S., & Gove, J. H. (2003). Perpendicular distance sampling: An alternative method for sampling downed coarse woody debris. *Canadian Journal of Forest Research, 33*(8), 1564–1579.

Williams, M. S., Valentine, H. T., Gove, J. H., & Ducey, M. J. (2005). Additional results for perpendicular distance sampling. *Canadian Journal of Forest Research, 35*(4), 961–966.

APPENDIX 1: PERFORMANCE METHOD

10.1 Applicability Conditions

This appendix is applicable under the following conditions:

1) The project meets all applicability conditions detailed in Section 4 of this methodology.

2) The project activities will produce continuous vegetative cover on any contiguous area exceeding one hectare allowing for clear spatial delineation the project area; and

3) The project's performance benchmark must be updated at each verification or every five years, whichever comes first.

10.2 Baseline Scenario

The baseline scenario is represented by the business-as-usual growth of carbon stocks, as observed on representative remotely sensed control plots located outside of any registered AFOLU project area. The baseline scenario is represented by business-as-usual changes in above-ground biomass in control plots. This approach creates the most plausible baseline scenario because remote sensing provides continual and quantifiable observations of changes in aboveground biomass allowing for the real-time comparison of project and baseline.

The business-as-usual changes in vegetation cover are represented by the performance benchmark, which is equal to the ratio of average change in stocking index, SI, of control plots to project plots. The control plots are appropriately matched to the project area based on similar biophysical, social and political conditions and historic stock trends (see below). SI in control plots is detected using remote sensing and do not need direct field measurement. The baseline is established at every verification period through the application of an updated performance benchmark. The application of the performance benchmark, as explained below, effectively excludes crediting of project activities that may be expected to be implemented without carbon incentives, based on comparative outcomes. It also ensures that credited projects produce performance improvements relative to the business-as-usual case (represented by the crediting baseline).

Note that all project and control plots referenced in the appendix are remotely sensed and will therefore be referred to as 'project plots' and 'control plots' from here forward in Appendix 1.

10.3 Performance Benchmark

The performance benchmark is determined by comparing the average rate of increase stocking index (SI) between project and control plots. Equation (A4) derives the performance benchmark for both demonstration of additionality and the crediting baseline. Equation (30) applies the performance benchmark for the crediting baseline. A performance benchmark is developed for

each project area, or in the case of grouped projects, a separate performance benchmark is developed for each annual cohort of instances. Performance benchmarks are monitored ex post, hence are dynamic. The approach to select control plots outlined below constitutes a matching approach widely used in impact evaluation in the environmental field (Ferraro & Hanauer, 2014). Matching approaches are not expected to produce exact matches for individual land parcels, but rather to produce robust estimates of impact for sample "populations" of matched pairs (controls and treatments).

An ex-ante estimate of the performance benchmark must be calculated referencing a value of $\Delta SI_{control,t}$ using the stocking indices for the historic period t=-10 to t=0 for the selected control plots (derived in Step 2 above).The project slope is derived from the growth and yield curve procedure provided in Section 8.2.9 of the methodology.

Assessing plots using remote sensing, does not involve direct estimation and reporting of carbon stocks. Remote sensing is used only to estimate relative stock change between control and project plots. Accounting of emission reductions and removals is treated in Section 8 and is dependent on direct field measurement.

10.4 Procedure to Define the Performance Benchmark

The steps for establishing the performance benchmark must be documented in the project description in sufficient detail so that they can be repeated and validated. All of the following steps must be fully documented as part of the monitoring plan for project and control plots, described in section 9.2 of the methodology.

Overview of Establishing the Performance Benchmark:

1) Starting at time t=0, or at time t > 0 where initial stock measurements occurred after the project start date. Select project plots via representative sampling.

2) For each project plot, select matched control plots:

   a) Delineate the donor pool using maps of categorical variables matching the project plot.

   b) Evaluate continuous matching covariates (including the historical trend in stocking index) on prospective control plots.

   c) Select k control plots most closely matching the project plot.

3) For the sample population of matched project and control plots, evaluate match quality and finalize matching.

Assessment of the Performance Benchmark at each monitoring event:

1) Monitor stocking index on project and control plots.

2) Derive slopes for accumulated time series (from time t = 0 to time t) of stocking indices estimated across the sample populations of project and control plots.

3) Calculate performance benchmark.

Step 1: Select project plots

The following must be performed for each annual cohort separately.

1) Divide the entire project annual cohort area into contiguous, non-overlapping units (project plots) ranging from 0.09 hectares (30 × 30 m) to 10 hectares in area. At least 75 percent of each unit must be within the project area boundary. Project plots may be represented by individual pixels or aggregates of pixels.

2) Select a representative sample of n = 30 or more project plots, via random or systematic, stratified, or un-stratified sampling.

Step 2: Select control plots for each project plot

1) Select donor pool area

Define donor pool area from within which control plots may be sourced, applying criteria in Table A1. The process to determine the eligible control area is implemented with a series of GIS overlays. The project may include other spatially explicit, categorical drivers of carbon regeneration or reforestation (e.g., land cover classifications), provided their inclusion is justified on a theoretically sound or empirically demonstrated basis (e.g., peer-reviewed study). Any geospatial datasets included must have resolution no coarser than 30 x 30 meters.

Table A1: Required factors and source data to delineate donor pool area, evaluated for time _t_ = 0. Time variant geospatial layers used must be current as of _t_ = 0, ±5 years.

Factor	Procedure and data source (GIS layer)
Jurisdictional boundary	Where the project area is within a subnational jurisdiction either registered under Jurisdictional and Nested REDD+ (JNR) or delineated by the national or subnational government for reporting REDD+ (e.g., delineated as a discrete Forest Reference Emission Level), the relevant jurisdictional boundary is the subnational jurisdiction (no lower than the second administrative level from the national level). Otherwise, the jurisdictional boundary used is the national boundary. Source: the GIS layer for the jurisdictional boundary must be from a published or official national government source.
Ecoregion	The donor pool area must exclude any areas not within the same ecoregion (biome level) as the project.

Factor	Procedure and data source (GIS layer)
Policy environment	The donor pool area must exclude any areas of the jurisdictional boundary (defined above) with presence/absence of any operating subnational government-funded program providing incentives for tree planting that differs from the project area. Operating government-funded program providing incentives for tree planting A currently (as of the relevant evaluation date) funded and implemented national or sub-national government policy/program providing monetary incentives for tree planting (e.g., USDA Conservation Reserve Program)
Outside any registered AFOLU project	Optionally, and as available, the donor pool area may exclude boundaries of any AFOLU projects registered under a carbon offset program. Source: kml files from project registries (e.g., Verra registry)
Land tenure	All land tenure classifications present in the project area must be represented in the donor pool. Exclude any areas with different land tenure classification than the project area. Land tenure classification should be sourced from published or official government sources. At a minimum, land tenure classification must distinguish between public and private lands. More precise classifications (e.g., indigenous reserves, concessions, private industrial lands) may be used where available. Source: published or official government source
Distance from project plot	Exclude areas beyond a 100 km radius of the centroid of the project plot.

2) Evaluate project plots

Once the donor pool area has been delineated applying the factors in Table A1, it is divided into non-overlapping units of sizes not exceeding ±20 percent of the mean size of project plots.

Quantify historic and initial conditions of SI via a time series analysis for a representative of control and project plots (Table A2). A regression must be run for the SI of each control and project plot as a function of time including at a minimum three time points:

- between t=-10 and t=-8
- between t=-8 and t=-1
- at t=0

Table A2: Required covariates for matching control plots to project plots (detailed guidance on each covariate provided in "Data and Parameters Monitored" below).

Matching covariate	Description
$SI_{t=0}$, $SI_{t=-10}$, etc.	Stocking indices from three or more time points during the historic period spanning 8–10 years immediately prior to the project start date, minimally including values for the beginning of the historic period (not before $t = -10$ and no later than $t = -8$) and for time $t = 0$.

For each control plot, calculate a multivariate distance metric, *MD* (e.g., Euclidean distance, Mahalanobis distance), across the vector of covariates (i.e., the minimum three time points referenced above), relative to the project plot.

3) Select control plots

To match control plots with project plots, apply a *k*-nearest neighbor optimal matching approach without replacement (i.e., control plots may not be matched to multiple project sample plots). The number of control plots matched to each project plot, *k*, is selected by the project proponent. *k* must be kept constant for each match (e.g., if *k*=5 for project plot A, *k* must remain 5 for the project lifetime).

Select the *k* control plots with the lowest multivariate distance metric values and derive relative weights proportional to the inverse of the multivariate distance metric value, that sum to 1 (Equation (A1)).

$$W_{control,i,j} = \frac{e^{-MD_{i,j}}}{\sum_{j=1}^{n_{i,j}} e^{-MD_{i,j}}} \tag{A1}$$

Where:

$W_{control,i,j}$	=	Weight of control plot *j* matched to project plot *i* (value between 0 and 1; dimensionless)
$MD_{i,j}$	=	Multivariate distance of control plot *j* relative to project plot *i* (dimensionless)
$n_{i,j}$	=	Number of control plots matched to project plot *i* (equal to *k* at project start date)

Step 3: Evaluate match quality and finalize matching

For the sample population of matched pairs (project plots and matched sets of control plots), evaluate match quality and finalize matching.

For each included matching covariate *x*, calculate the standardized difference of means (SDM) as:

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

Where:

SDM	=	Standardized difference of means
$\overline{x}_{wp,x}$	=	Mean value of covariate x in the population of project plots
$\overline{x}_{bsl,x}$	=	Mean value of weighted sums of covariate x in the population of matched sets of control plots
$\sigma^2_{wp,x}$	=	Standard deviation of covariate x in the population of project plots
$\sigma^2_{bsl,x}$	=	Standard deviation of covariate x in the population of control plots

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, the final selection of control plots and their respective weights are then fixed, and UTM coordinates recorded, for the duration of the crediting period. Where the overall match is not deemed valid, Steps 1, 2, and 3 are repeated after:

a) Progressively expanding the radius of the donor pool in 100 km increments, and/or

b) Decreasing the k value for all project plots, until a valid overall match is achieved.

Step 4: Monitor control and project plots

The performance benchmark is derived from monitoring stocking index, *SI*, in control and project plots.

In each control and project plot, assess and record initial *SI* value. At each monitoring event, remove any control plots deemed invalid due to their location in areas no longer matching the project area in terms of being either:

a) Subject to any operating subnational government-funded program providing incentives for tree planting, implemented during the evaluation period, to which the project area is not subject; or

b) Within the boundaries of any AFOLU projects registered under a carbon offset program (optional).

Where a control plot has been deemed invalid, the plot is excluded and replaced from the donor pool selected in Step 2. Weights of the control plots must be recalculated to sum to 1. For each remaining valid control and project plot, re-evaluate *SI*, consulting the most recent imagery (see *SI* parameter table for guidance on temporal constraints on imagery sourcing).

Step 5. Derive and evaluate slopes for time series of stocking indices

Assemble accumulated time series of $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$ values from time $t = 0$ to time t, estimated across the sample populations of project and control plots. The derivation of *SI* for the

monitoring interval must include at minimum three time steps: t, t=0, and at least one time point between t and t=0.

To be included in the dataset, *SI* values must be available at time *t* for the project plot *i* and all of its matched control plots *i,j*. Where *SI* values for plots within a matched set are not available at time *t,* (e.g., due to cloud cover or temporary sensor issues), the matched set of project and control plots (*i*) must not be used in the derivation of $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$ at each time *t*. A minimum of n=30 project plots must be achieved to have a representative sample of the area.

The rate of increase in stocking index in the control and project plots, $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$, is calculated as the slope of the weighted linear regression of the accumulated time series of *SI* values for the respective population of plots, see Example 1 below.

Weights of *SI* values for control plots in the time series are calculated as:

$$W_{control,i,j,t} = W_{control,i,j} \times \frac{1}{\sum_{t=0}^{t} n\_rs_t} \tag{A3}$$

Where:

$W_{control,i,j,t}$	=	Weight of control plot *j* matched to project plot *i* at time *t* (dimensionless)
$W_{control,i,j}$	=	Weight of control plot *j* matched to project plot *i* (value between 0 and 1; dimensionless)
n_rs_t	=	Number of project plots with k matched control plots (*i,j*) with values assessed at time *t*

Weights of *SI* values for project plots in the time series are calculated as:

$$W_{wp,i,t} = \frac{1}{\sum_{t=0}^{t} n\_rs_t} \tag{A4}$$

Where:

$W_{wp,i,t}$	=	Weight of project plot *i* at time *t* (dimensionless)
n_rs_t	=	Number of project plots and matched control plots (*i,j*) with values assessed at time *t*

The significance of the difference between $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$ is evaluated with a *Z* test as follows:

$$Z = \frac{\Delta SI_{wp,t} - \Delta SI_{control,t}}{\sqrt{SE_{\Delta SI\_wp,t}^2 + SE_{\Delta SI\_control,t}^2}} \tag{A5}$$

Where:

Z	=	*Z* value (unitless)

$\Delta SI_{control,t}$	=	Average annual increase (slope) in stocking index SI in control plots through time t
$\Delta SI_{wp,t}$	=	Average annual increase (slope) in stocking index SI in project plots through time t
$SE^2_{\Delta SI\_wp,t}$	=	Squared standard error of the average annual increase (slope) in stocking index SI in project plots through time t
$SE^2_{\Delta SI\_control,t}$	=	Squared standard error of the average annual increase (slope) in stocking index, SI, in control plots through time t
t	=	1, 2, 3, …, t years elapsed since the project start date

Where the absolute value of Z is equal to or exceeds 1.96, parameters $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$ are deemed significantly different.

Projects employing a long-term average must reference the most recent version of the *VCS Standard*.

Step 6: Derive performance benchmark

Where parameters $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$ are not deemed significantly different ($|Z| < 1.96$, see above), PB_t is set equal to 1.

Where parameters $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$ are deemed significantly different ($|Z| \geq 1.96$, see above), calculate the performance benchmark as the ratio of average change in SI in control plots to average change in SI in the project area (Equation (A6)). Where the slope coefficient of the control plots, $\Delta SI_{control,t}$, is insignificant ($P > 0.05$) or less than zero, $\Delta SI_{control,t}$ is set equal to zero in Equation (A6).

$$PB_t = \Delta SI_{control,t} \times \frac{1}{\Delta SI_{wp,t}} \tag{A6}$$

Where:

PB_t	=	Performance benchmark for the monitoring interval ending at year t, dimensionless
$\Delta SI_{control,t}$	=	Average annual increase in stocking index, SI, in control plots through time t
$\Delta SI_{wp,t}$	=	Average annual increase in stocking index, SI, in project plots through time t
T	=	1, 2, 3, …, t years elapsed since the project start date

Example 1: Simplified performance benchmark with one project plot and 10 matched control plots

T	Control plot i,j	$W_{control,i,j,t=0}$	$SI_{control,i,j,t}$	$W_{control,i,j,t=5}$
0	1_1	0.20	0.08	0.10
0	1_2	0.17	0.04	0.08
0	1_3	0.14	0.01	0.07
0	1_4	0.11	0.04	0.06
0	1_5	0.09	0.06	0.05
0	1_6	0.09	0.00	0.04
0	1_7	0.08	0.02	0.04
0	1_8	0.06	0.10	0.03
0	1_9	0.05	0.10	0.03
0	1_10	0.01	0.09	0.00
5	1_1	0.20	0.07	0.10
5	1_2	0.17	0.22	0.08
5	1_3	0.14	0.13	0.07
5	1_4	0.11	0.22	0.06
5	1_5	0.09	0.05	0.05
5	1_6	0.09	0.19	0.04
5	1_7	0.08	0.13	0.04
5	1_8	0.06	0.14	0.03
5	1_9	0.05	0.20	0.03
5	1_10	0.01	0.18	0.00
		$\Delta SI_{control,t=5}$	0.02	*Fitted weighted least squares*

T	Project plot i	$W_{wp,l,t}$	$SI_{wp,l,t}$
0	1	1	0.05
5	1	.5	0.80
		$\Delta SI_{wp,t=5}$	0.15
		PB_t	13%

Figure 3: Example of matching (ex ante) and monitoring (ex post) control plots (n = 100) and project plots (n = 100). Each data point represents the mean SI evaluated at time t. Here, $\Delta SI_{wp,t=16}$ = 0.02, and $\Delta SI_{control,t=16}$ = −0.0008 (not significantly different from zero), Z = −27.53 (slopes are significantly different) from $PB_{t=16}$ = 0.
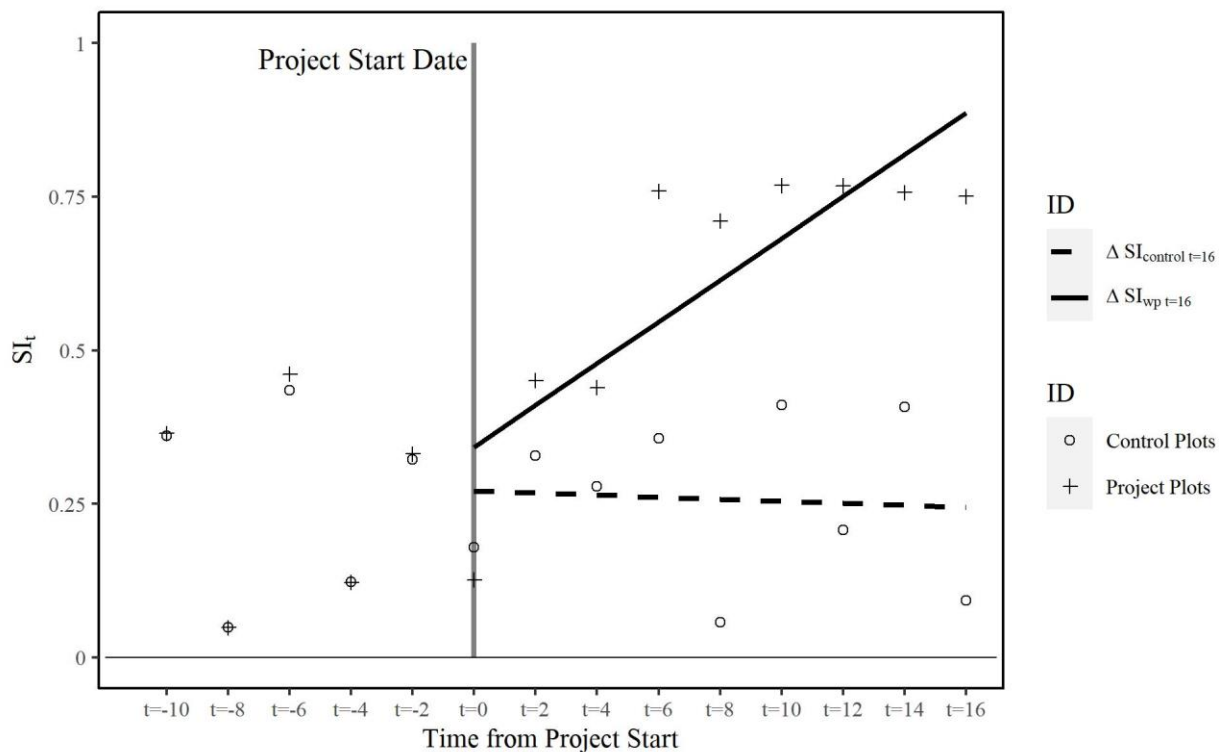
Example 2: Simplified performance benchmark over time with one project plot and one matched control plot

With project: steady growth			Control: agriculture with fallow cycle			
t	$SI_{wp,t}$	$\Delta SI_{wp,t}$	t	$SI_{control,t}$	$\Delta SI_{control,t}$	PB_t (%)
0	0.00		0	0.00		
1	0.03	0.03	1	0.00	0.00	9
2	0.09	0.04	2	0.01	0.00	11
3	0.15	0.05	3	0.02	0.01	13
4	0.20	0.05	4	0.03	0.01	15
5	0.26	0.05	5	0.00	0.00	8
6	0.32	0.05	6	0.00	0.00	5
7	0.38	0.05	7	0.01	0.00	4
8	0.43	0.05	8	0.02	0.00	4
9	0.47	0.05	9	0.03	0.00	5
10	0.52	0.05	10	0.00	0.00	4
11	0.56	0.05	11	0.00	0.00	3
12	0.60	0.05	12	0.01	0.00	3

13	0.63	0.05	13	0.02	0.00	3
14	0.67	0.05	14	0.03	0.00	3
15	0.70	0.05	15	0.00	0.00	3
16	0.72	0.05	16	0.00	0.00	2
17	0.75	0.05	17	0.01	0.00	2
18	0.77	0.05	18	0.02	0.00	2
19	0.79	0.05	19	0.03	0.00	3
20	0.81	0.05	20	0.00	0.00	2

10.5 Data and Parameters Monitored

Data/Parameter	$SI_{control,t}$ and $SI_{wp,t}$
Data unit	Unspecified
Description	Stocking index in scenario (control plot j or project plot i) at time t
Equations	(A5)
Source of data	SI is an unspecified remote sensing metric that has demonstrated correlation with terrestrial aboveground carbon stocks (e.g., normalized difference fraction index[15] from Landsat imagery, average canopy height derived from LiDAR or percentage canopy cover interpreted from aerial imagery). Variability due to seasonality must be minimized (e.g., by setting a target data collection period at the project start and collecting all monitoring imagery from within that period). Target period should coincide with minimal seasonal phenological variation, and where passive remote sensors are employed this should coincide with months of lowest cloud cover. Spatial scale: Divide the entire project area into polygons from 0.09 hectares (30 × 30 m) to 10 hectares in area. Polygons must be of equal size with at least 75 percent of each polygon located within the project area boundary. project plots may be represented by individual pixels or aggregates of pixels.
Description of measurement methods	

---

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

and procedures to be applied	
Frequency of monitoring/recording	At least annually
QA/QC procedures to be applied	The remote sensing metric applied must: 1) Have significant correlation with terrestrial carbon stocks, at least with aboveground biomass, that has been previously substantiated with published or peer-reviewed studies 2) Be validated with direct measurements from the project region (collected from within the project ecoregion; ecoregion defined at the biome level[16]). Processing and analysis of remote sensing data must apply established best practices, such as those found in: Global Forest Observations Initiative (2016). *Integration of remote-sensing and ground-based observations for estimation of emissions and removals of greenhouse gases in forests: Methods and guidance from the Global Forest Observations Initiative, edition 2.0*. U.N. Food and Agriculture Organization.[17] Mitchell, A. L., Rosenqvist, A. & Mora, B. (2017). Current remote sensing approaches to monitoring forest degradation in support of countries measurement, reporting and verification (MRV) systems for REDD+. *Carbon Balance and Management, 12*, 9.[18]
Purpose of data	Selection of control plots and derivation of performance benchmark for the area-based approach
Calculation method	
Comments	Note that *SI* may be derived using different remote sensing metrics for the selection of control plots and for monitoring the performance benchmark. It is expected that the same remote sensing technology may not be available for both the historical analysis (selection of control plots) and monitoring ex post. The same remote sensing metric must be used for monitoring *SI* ex post in both control plots and project sample plots. Where

---

[16] https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world

[17] https://www.fs.usda.gov/research/treesearch/56461;https://www.fs.fed.us/rm/pubs_journals/2020/rmrs_2020_espejo_a001.pdf

[18] https://cbmjournal.biomedcentral.com/articles/10.1186/s13021-017-0078-9

more accurate remote sensing metrics become available over time, the remote sensing metric used for monitoring *SI* ex post may be changed when:

1) The new metric offers equivalent or better accuracy (in terms of correlation with terrestrial carbon stocks);

2) It is possible to harmonize the new metric with the previous metric, applying procedures from peer-reviewed literature[19] to ensure data continuity and remove sources of misalignment (e.g., geometric, radiometric and/or spectral artifacts) introduced by the new metric;

3) The procedure to harmonize the new metric incorporates temporally coincident observations of both (previous and new) remote sensing metrics from the project and control plots from within an overlap interval of not less than two years, or as prescribed by the procedure.

[19] e.g., https://www.usgs.gov/landsat-missions/harmonizing-landsat-archive

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

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

Individual carbon pools and emissions sources may be neglected if the relative contribution of the decreases in a carbon pool, or increases in an emissions source is less than 5 percent of the sum total of all decreases in carbon pools and increases in emissions, or less than 5 percent of carbon dioxide removals, whichever is smaller.

$$RC_{Es} = \frac{Es}{\sum_{s=1}^{S} Es} \tag{A7}$$

Where:

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

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

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

The GHG emissions, possible decreases in carbon pools and leakage emissions not included in the summation are considered insignificant where their sum is lower than five percent of carbon dioxide removals. Otherwise, the procedure described above must be continued beyond the threshold of 0.95 until the above condition is met.

DOCUMENT HISTORY

Version	Date	Changes
v1.0	28 Sep 2023	Initial version released
C&C issued for v1.0	14 May 2025	Equations (15), (16), (20), (21), (22), 23) and (24), (25), (26) using "in the monitoring interval ending in year t" instead of "in year t" Corrections to equations (30), (31) and added equation (32) in Section 8. Clarification on applicability of the methodology in areas that have existing forest cover as long as they are not managed forests