VCS Methodology

VM0047

AFFORESTATION, REFORESTATION, AND REVEGETATION

Version 1.1

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

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1 SUMMARY DESCRIPTION

Additionality, Crediting Method,[1] and Mitigation Outcome	
Additionality	Performance Method (area-based) or Project Method (census-based)
Crediting Baseline	Performance Method (area-based) or Project Method (census-based)
Mitigation Outcome	Removals

This 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).

1.1 Summary of the Area-based Approach

The area-based approach applies to ARR projects that change land cover from non-forest to forest or enhance stocks in existing forests. Detectable changes in vegetative cover measured using remote sensing and plot-based sampling serve as the basis for quantifying carbon removals. The area-based approach:

1) uses traditional plot-based sampling methods to estimate biomass per unit area, scaling these estimates to the project level based on the total project area within the boundary.

2) uses a dynamic performance benchmark to assess additionality and determine the crediting baseline at each verification. The performance benchmark is derived from ex-post observations that compare the change in vegetative stocking index (SI) between remotely sensed project and matched control plots.

3) does not apply to projects that can use the census-based approach.

4) applies *VMD0054 Module for Estimating Leakage from ARR Activities* to quantify leakage. The module 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) and other actors (market leakage).

[1] See Section 7 for additional information.

1.2 Summary of the Census-based Approach

The census-based approach applies to ARR projects that do not occur in forests and do not result in land use changes. This approach enables the inclusion of ARR activities that would otherwise be difficult to quantify under the area-based approach. The census-based approach:

1) applies only to projects that involve direct planting.
2) limits planting density to a maximum of 50 planting units per hectare.
3) uses a complete census of all planting units (established as *N,* the total number of planting units) at t=0.
4) estimates biomass through sampling and measurement of planting units, then scales to the project level using the number of planting units (*N*) as a multiplier.
5) uses a project method to demonstrate additionality and determine the crediting baseline.
6) is exempt from applying a leakage deduction because projects must not result in a change to existing land use.

2 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:

- *CDM 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*

3 DEFINITIONS

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

Accounting boundary
Applies to census-based projects as the specific spatial area within the project boundary where GHG emissions, carbon dioxide removals, and GHG emission reductions are quantified. The accounting boundary exists entirely within the project boundary and is limited to individual planting units. It excludes soil organic carbon, litter, and non-woody biomass outside those units.

Control plot
Plot located outside of the project area that is selected based on its similarity to a project plot and that is monitored via remote sensing techniques.

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

Land use change date
Date on which a change in land use occurred (e.g., cessation of grazing, establishment of an exclosure).

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

Matching covariates
Continuous variables from 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). It is 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 under the census-based approach.

Pre-existing woody biomass
Woody biomass in the project area prior to project implementation, including aboveground, belowground, and deadwood (where included as a relevant pool).

Project plot
Remotely sensed plot of up to 10 ha representatively sampled from the project area, from which the stocking index (SI) is evaluated.

Site preparation
ARR project activities undertaken prior to any planting that remove or disturb pre-existing biomass or soil in the project area.

Stocking index (SI)
An unspecified remote sensing metric with demonstrated correlation with terrestrial aboveground carbon stocks (e.g., normalized difference fraction index – NDVI - from Landsat imagery, average canopy height derived from light detection and ranging (LiDAR)).

Woody biomass
Biomass in plants with hard, lignified stems (e.g., trees, shrubs, palms, and bamboo). Includes aboveground and belowground woody biomass pools.

4 APPLICABILITY CONDITIONS

This methodology applies to ARR activities that establish, increase, or restore vegetative cover. Eligible project activities may involve direct planting, seeding, or assisted natural regeneration techniques, provided they lead to a measurable increase in vegetative cover. The applicability conditions for the area-based and census-based approaches are mutually exclusive. Each project activity instance must fully meet the applicability conditions of either the area-based approach or the census-based approach. A project may incorporate multiple instances that apply different approaches, provided that those instances are clearly separated by a minimum 10-meter buffer within the project boundary.

4.1 General Applicability Conditions

The following applicability conditions must be met by all projects using this methodology (area-based, census-based, or a combination of both approaches):

1) Project activities increase vegetative cover.
2) Where area-based and census-based approaches are used together, they are applied in non-overlapping areas defined at the project start (see Section 5 on the delineation of spatial boundaries to ensure non-overlap).
3) For lands enrolled in a project, the quantification approach is selected at the project start date and used for the entire project crediting period.
4) The project start date is documented as the earliest of the following:
    a) The date on which site preparation activities began;
    b) The land use change date
5) Where projects take place on organic soils or wetlands, ARR activities are developed using a multiple project activity design, applying this methodology to account for aboveground biomass and using a Wetland Restoration and Conservation methodology (e.g., *VM0036 Methodology for Rewetting Drained Temperate Peatlands*) to account for other carbon pools.

4.2 Area-based Approach Applicability Conditions

The following applicability conditions must be met by all projects using the area-based approach:

1) Project activities involve direct planting activities (e.g., manual planting, broadcast seeding), indirect activities associated with assisted natural regeneration (e.g., liana cutting, weed management, or barriers that prevent animal grazing), or a combination of direct and indirect activities.

2) Project proponents establish a $t = 0$ carbon stock estimate for all significant carbon pools. The method for establishing $t = 0$ estimates depends on the activity that initiates the project start date.[2]

    a) Where the project start date is initiated by site preparation (e.g., clearing invasive species), the following conditions must be met:

        i) Before site preparation, project proponents establish $t = 0$ carbon stock estimates for all significant carbon pools[3].

        ii) To ensure accuracy, $t = 0$ estimates are established no more than two years before the start date (e.g., if the start date is 2025, plots must have been established no earlier than 2023).

        iii) Where plot-based measurements are not established before site preparation, a remote sensing-based estimate found in Section 8.2.1.2 may be used, but only for pre-existing woody biomass.

Note – Remote sensing estimates are only eligible to use for estimates of pre-existing aboveground and belowground biomass and must not be used to establish a t *= 0 estimate for any other carbon pool (e.g., SOC, dead wood). Where any other significant carbon pool is impacted during site preparation (e.g., SOC impacted due to plowing at depth greater than 25 cm, or the removal of dead wood offsite) and a* t *= 0 measurement was not established, the project is ineligible.*

    b) Where the project start date is defined by a land use change date or where the project start did not include site preparation that caused a significant decrease in carbon stocks in monitored carbon pools (e.g., pit planting without clearing existing vegetation) the following conditions must be met:

        i) The project proponent establishes $t = 0$ estimates within two years after the project start date (e.g., if the start date is 2025, plots must be established by 2027).

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[2] Establishment of project plots does not constitute the project start date.

[3] This includes allowing the removal of dead wood offsite as long as a t=0 measurement is established and the removal is accounted for as an immediate project emission.

ii) Plot-based sampling occurs for all significant carbon pools.

iii) Evidence is provided to demonstrate that site preparation did not involve clearing, burning, or mechanical disturbance of existing vegetation that would significantly reduce monitored carbon pools. Evidence may include, but is not limited to, georeferenced photos, field survey data, satellite imagery, and signed attestations from landowners.

3) Leakage must be monitored and quantified using *VMD0054*. It must not be assumed to be *de minimis*.

4.3 Census-based Approach Applicability Conditions

The following applicability conditions must be met by all projects using the census-based approach:

1) The project activity only includes direct planting.

2) The pre-project land use is maintained throughout the project lifetime (e.g., where projects occur on agricultural land, agricultural production continues).

3) Planting density does not exceed 50 planting units per hectare. The planting density limit applies proportionally to the size of each instance:

   a) Where an instance is less than one hectare or includes part of a hectare (e.g., 0.50 ha or 1.50 ha, respectively), the planting density is scaled proportionally to the size of the instance. For example, an instance of 0.50 hectares may include no more than 25 planting units.

   b) In instances larger than one hectare, planting is dispersed to maintain compliance with the 50 planting units per hectare limit across the entire instance (e.g., in a 10-hectare instance, up to 500 planting units may be planted, but must not be concentrated in a single hectare or portion of the instance).

4) The establishment of a complete census of all planting units marks the start of the project and is t = 0. The census is conducted to establish N, the total number of planting units. Only planting units planted by the project proponent are included in the census. Existing vegetation is not included in the census and does not count toward the 50 planting units per hectare density threshold.

5) Where planting units have died, plantings may be replanted provided N does not exceed 50 live planting units per hectare established by the project activity.

6) Individual planting units of woody biomass are clearly defined (e.g., tree, shrub, bamboo clump) and identifiable in the field. One of the following identification approaches must be used:

a) GPS points: Project proponents must ensure that the spacing between individual planting units is greater than or equal to the positional accuracy of the Global Positioning System (GPS) units used for geolocating each planting unit. For example, if the positional accuracy of the GPS is five meters, the minimum spacing between planting units must be greater than or equal to five meters.

b) Physical markers: Each planting unit must be marked with a durable, in-field physical identifier bearing a unique ID. These markers must be clearly visible and easily located during verification activities.

7) Where a planting unit cannot be located during a monitoring event, it is conservatively assumed that the planting unit has died.

8) The project activity occurs:

a) within an area with less than 10% pre-existing woody biomass cover; and/or

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

9) Soil disturbance from project activities[6] (e.g., site preparation) meets the following conditions:

a) Soil disturbance is permitted only at the time of planting. Where replanting or additional waves of planting occur, soil disturbance is permitted under the same conditions.

b) Planting techniques that cause localized soil disturbance, such as pit planting, may exceed a depth of 25 cm.

c) Where planting involves soil inversion (e.g., plowing), the depth must not exceed 25 cm (such as that caused by a moldboard plow) and may only occur once during the project crediting period.[7]

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[4] 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, Chapter 3.

[6] In accordance with Section 4.3(2) above, the pre-project land use must be maintained throughout the project lifetime. Plowing and other soil disturbance may continue as part of ongoing land use activities (e.g., agricultural production) where they are not associated with the project activity. Only soil disturbance directly related to ARR activities is subject to the restrictions outlined in Section 4.3(9).

[7] Where a census-based project occurs on lands used for agriculture or other purposes where soil inversion is required, soil inversion for purposes other than planting trees may continue and would not be considered part of the project activity.

4.4 Exclusion Conditions

The conditions specified below highlight eligibility conditions where clarification is often needed. These exclusion conditions are not exhaustive. Project proponents are responsible for ensuring full compliance with all VCS Program rules and requirements in addition to respecting the exclusion conditions. For example, where projects take place on land that was degraded within 10 years of the project start date, exclusion conditions are specified in Section 3.19 of the *VCS Standard, v4.7*.[8]

4.4.1 Area-based Approach Exclusions

This methodology is not applicable for projects using the area-based approach under the following conditions:

1) 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.
2) Clearing of pre-existing woody biomass involves timber harvesting or results in degradation of native ecosystems.
3) The project is planting fewer than 50 planting units per hectare and could use the census-based approach.

4.4.2 Census-based Approach Exclusions

This methodology is not applicable for projects using the census-based approach under the following conditions:

1) Woody biomass, which serves a similar purpose as the planting units in the project, has been removed within the last 10 years (confirmed via pre-project photos and/or attestation).
2) Soil disturbance from the project activity involves soil inversion to a depth exceeding 25 cm (e.g., that would result from a moldboard plow).

5 PROJECT BOUNDARY

Where area-based and census-based approaches are used in the same project, project proponents must ensure that accounting boundaries do not overlap.

[8] Section 3.19.29(2) in the *VCS Standard, v4.7* stipulates: *"Where the ecosystem was degraded within 10 years of the project start date of any ARR, ALM, WRC, or ACoGS activity, evidence shall be provided that the ecosystem was not degraded due to the project activity (e.g., that the degradation occurred in the pre-project land use due to natural disasters such as hurricanes or floods)."*

Project proponents must refer to both Tables 1 and 2 below for selected carbon pools in the project boundary in baseline and project scenarios when combining the area-based and census-based approaches. Appendix 2 of this methodology must be applied to test the significance of carbon pools and greenhouse gas (GHG) emission sources to determine whether they may be deemed *de minimis*.

5.1 Area-based Approach Carbon Pools

The accounting boundary for the area-based approach 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 for the area-based baseline and project scenarios are listed in Table 1.

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 where the project activity significantly reduces the carbon pool as per Appendix 2. Otherwise, this carbon pool is optional.
Belowground woody biomass	Yes	Major carbon pool
Belowground non-woody biomass	Yes/Optional	Must be included where the project activity significantly reduces the carbon pool as per Appendix 2. Otherwise, this carbon pool is optional.
Dead wood	Yes/Optional	Must be included where the project activity involves removal of dead wood as part of site preparation, or where the project activity significantly reduces the carbon pool as per Appendix 2. Otherwise, this carbon pool is optional.
Litter	Yes/Optional	Must be included where the project activity significantly reduces the carbon pool as per Appendix 2. Otherwise, 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):

Carbon Pool	Included?	Justification/Explanation
		1) occurs more than once during the project crediting period. 2) occurs and the project activity involves harvesting. 3) 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, inclusion of this carbon pool is optional.
Harvested wood products	Excluded	Conservative to exclude

5.2 Census-based Approach Carbon Pools

In the census-based approach, each planting unit has a 10-meter radius buffer. Together, these buffers define the accounting boundary of a project activity instance. Buffers may overlap within the same instance but must not overlap with the boundary of another census- or area-based instance. This separation between instances prevents double counting.

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

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

Carbon Pool	Included?	Justification/Explanation
Harvested wood products	Excluded	Conservative to exclude

5.3 GHG Sources

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 under both area- and census-based approaches

Source		Gas	Included?	Justification/Explanation
Baseline	Burning of biomass (natural or anthropogenic causes)	CO_2	No	Conservative to exclude
		CH_4	No	Conservative to exclude
		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

6.1 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.

6.2 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 10%; and
2) occur in an area subject to continuous cropping, or in "settlements," or "other lands" land use categories.[9]

Where a project meets these criteria, it may be assumed that afforestation, reforestation, or revegetation will not occur without project interventions and the crediting baseline is set to zero.

7 ADDITIONALITY

Project proponents must apply a performance method (area-based approach) or a project method (census-based approach) to demonstrate additionality.

7.1 Area-based Approach

Project proponents using the area-based approach must apply the following additionality demonstrations:

- Regulatory surplus
- Performance benchmark
- Investment analysis[10]

7.2 Census-based Approach

Project proponents using the census-based approach must apply the following additionality demonstrations:

- Regulatory surplus

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[9] Land use category as defined by the *IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4, Chapter 3

[10] The investment barrier analysis is in addition to the regulatory surplus check and the performance benchmark for the area-based approach. It is not required where area-based projects do not generate revenues or receive financial incentives from sources other than the sales of carbon credits.

- Investment analysis[11]
- Common practice

7.3 Additionality Demonstrations

7.3.1 Regulatory Surplus

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

7.3.2 Performance Benchmark

The performance benchmark must be established following the procedures outlined in Appendix 1 and is applicable to the area-based approach only.

Where parameters $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$ are deemed significantly different (via Z test in Appendix 1 Equation (A7)), the project demonstrates additionality for the performance benchmark.

To demonstrate additionality at validation, project proponents must apply an ex-ante calculation to demonstrate an expected difference between modeled performance of the project and the forecasted performance benchmark. Additionality must be reassessed at each verification using the Z test in Appendix 1, Equation (A7).

7.3.3 Investment Analysis

Project proponents applying an investment analysis to assess additionality must use a benchmark analysis or investment comparison analysis and must apply the procedures and requirements in Step 3 of the most recent version of VCS tool *VT0008 Additionality Assessment*.[12]

7.3.4 Common Practice

The common practice analysis is applicable to the census-based approach only. The following steps must be taken to demonstrate that without carbon finance the project activity is not common practice:

1) Define the ARR project activity (e.g., tree planting).
2) Identify the geographic domain with a similar policy (and market, as available) environment as the project area. The geographic domain is first defined as the national boundary. Where national or subnational programs provide incentives for afforestation,

[11] The investment barrier analysis is always required for census-based projects.

[12] Section number from *VT0008 Additionality Assessment, v1.0*

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) Identify and explain any essential distinctions between the proposed project and similar activities. Such essential distinctions may include significant changes in circumstances, such as new barriers that have emerged or the end of promotional policies, that affect implementation of the proposed project activity compared to other similar activities. The distinction must be essential and verifiable. Essential distinctions may be related to, for example, changes in access to land or inputs, subsidies or other financial incentives, emergence of new barriers, differences in market access, infrastructure, labor availability, and biophysical conditions (e.g., climate, slope, or soil type).

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

6) Calculate the (cumulative) adoption rate (as a percentage) of the project activity by landowners who have not received carbon finance revenue (e.g., are 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 practice. Where the adoption rate is equal to or higher than 15%, the project activity is common practice and is not additional.

Alternatively, statistics on ARR activities derived from data collected within five years of the project start date may be used for this demonstration provided they are relevant to the project area, do not distinguish between activities incentivized by and not incentivized by carbon finance (thus are conservative), and are publicly available as:

a) agricultural census or other government data (e.g., survey data);

b) peer-reviewed scientific literature; or

c) independent research or reports compiled by industry associations, with full and transparent methods and documentation of results.

8 QUANTIFICATION OF REDUCTIONS AND REMOVALS

8.1 Baseline Emissions

8.1.1 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 8.6).

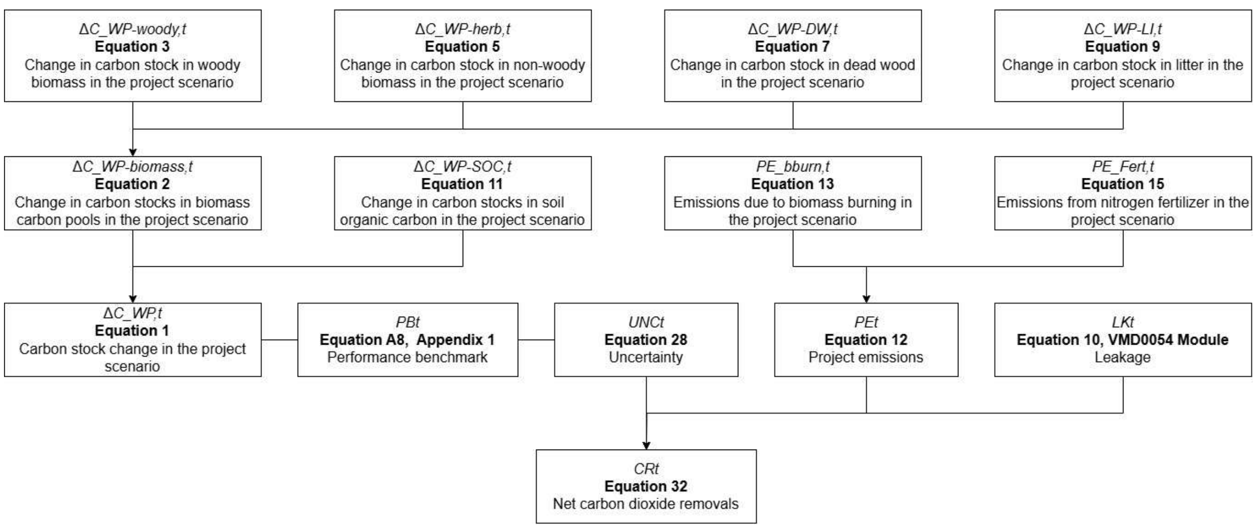
8.1.2 Census-based Approach

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

8.2 Area-based Project Emissions

The calculations of carbon stock changes and project emissions for the area-based approach are summarized in Figure 1.

Figure 1. Summary of calculations for area-based approach



8.2.1 Area-based Project Carbon Stock Changes

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

$$\Delta C_{WP,t} = (\Delta C_{WP-biomass,t} + \Delta C_{WP-SOC,t}) \times \frac{44}{12} \tag{1}$$

Where:

$\Delta C_{WP,t}$ = Project carbon stock change through year *t* (t CO_2e)

$\Delta C_{WP\text{-}biomass,t}$	=	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 soil organic carbon 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

$$\Delta C_{WP-biomass,t} = \Delta C_{WP-woody,t} + \Delta C_{WP-herb,t} + \Delta C_{WP-DW,t} + \Delta C_{WP-LI,t} \tag{2}$$

Where:

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

8.2.1.1 Area-based Quantification of Woody Biomass

The net carbon stock change in woody biomass in the area-based 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	=	Project 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.

8.2.1.2 Area-based Quantification of Pre-existing Woody Biomass

Quantification of pre-existing woody biomass is required under the area-based approach. The stock difference method is used to quantify carbon stock changes and requires a $t = 0$ estimate. A $t = 0$ estimate of pre-existing biomass must be established using one of the following approaches, depending on the start date and availability of plot-based sampling:

1) Plot-based sampling before site preparation is the preferred method and must be used whenever possible.

2) Where the project start date is based on a land use change date and plots could not be established beforehand, or where site preparation did not disturb pre-existing woody biomass, plots may be established and measured within two years after the project start date and used as the $t = 0$ estimate.

3) Where pre-existing woody biomass was disturbed before plot-based sampling, a remote sensing-based estimate may be used. This is allowed only where the project proponent demonstrates that no other significant carbon pools were affected during site preparation. Other carbon pools (e.g., SOC, dead wood, non-woody biomass) must not be estimated using remote sensing. Where a $t = 0$ estimate was not made, pools must either be eligible to be conservatively excluded or not have been disturbed. The remote sensing estimate of pre-existing woody biomass must meet the following conditions:

   a) The model predicts aboveground woody biomass using a stocking index-based regression model (see Appendix 1).

   b) The upper 90% confidence bound of the model's prediction interval is used as the $t = 0$ biomass estimate to account for uncertainty.

   c) The model is significantly correlated with aboveground biomass, supported by published or peer-reviewed studies, or statistically validated with direct measurements from the same ecoregion as the project's ecoregion.[13]

[13] As defined in the WWF Terrestrial Ecoregions of the World database. Available at: https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world

d) The spatial resolution is at least as fine as that of the remote sensing approach selected for the stocking index and meets all requirements listed in the parameter table for the stocking index in Appendix 1.

The removal of pre-existing woody biomass is allowed as part of site preparation where all of the following conditions are met:

i) A t = 0 estimate has been established through plot-based sampling or remote sensing.

ii) The biomass removed from the project site is considered a waste product with no commercial value.

iii) Removal does not involve the clearing or harvesting of natural forests (primary or secondary), native tree species, or commercially viable timber species.

Where a project meets these requirements, the removal of pre-existing biomass does not constitute a harvesting activity and therefore does not require the project to apply the long-term average. However, this does not preclude the application of the long-term average if harvesting occurs at any point in the future.

8.2.1.3 Area-based Quantification of Non-Woody Biomass

$$\Delta C_{WP-herb,t} = A \times (C_{WP-herb,t} - C_{WP-herb,t=0}) \quad (5)$$

$$C_{WP-herb,t} = DM_{WP-herb,t} \times CF \quad (6)$$

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

8.2.1.4 Area-based Quantification of Dead Wood

Project proponents must establish a t = 0 estimate of dead wood through plot-based sampling before any disturbance (e.g., removal, burning, piling, or masticating). The plot-based sampling must be conducted before site preparation and no more than two years prior to the project start date. Changes in dead wood due to offsite removal, burning, relocation, or disturbance must be quantified using the stock difference method to ensure accurate accounting.

Disturbance of dead wood pools as part of project activities (e.g., site preparation) prior to the establishment of plot-based sampling may make the project ineligible, per the applicability condition in Section 4.2(2).

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

$$\Delta C_{WP-DW,t} = A \times (C_{WP-DW,t} - C_{WP-DW,t=0}) \quad (7)$$

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 the project scenario in year *t* (t C/ha)
t	=	1, 2, 3, …, *t* years elapsed since the project start date

Dead wood carbon stock includes standing dead wood that is fully dead (i.e., absence of green leaves and green cambium) and lying dead wood and is estimated as follows:

$$C_{WP-DW,t} = (B_{SDW,t} + B_{LDW,t}) \times CF \quad (8)$$

Where:

$C_{WP\text{-}DW,t}$	=	Average carbon stock in dead wood in the project scenario 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

8.2.1.5 Area-based Quantification of Litter

The change in carbon stock in litter is estimated as follows:

$$\Delta C_{WP-LI,t} = A \times (C_{WP-LI,t} - C_{WP-LI,t=0}) \quad (9)$$

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

$$C_{WP-LI,t} = DM_{WP-LI,t} \times CF \tag{10}$$

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

8.2.1.6 Area-based Quantification of Soil Organic Carbon

Stocks of SOC are estimated from direct measurements. The change in SOC stock in the project scenario is estimated as follows:

$$\Delta C_{WP-SOC,t} = A \times \left(C_{WP-SOC,t} - C_{WP-SOC,t=0}\right) \tag{11}$$

Where:

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

8.2.2 Area-based Quantification of Emissions from Biomass Burning and Fertilizer Use

Total project emissions in the area-based approach are estimated as:

$$PE_t = PE_{bburn,t} + PE_{fert,t} \tag{12}$$

Where:

PE_t	=	Project emission from biomass burning and fertilizer use in the monitoring interval ending in year t (tCO2e)
$PE_{bburn,t}$	=	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 Area-based Quantification of Emissions from Biomass Burning

$$PE_{bburn,t} = A_{burn,t} \times \sum_{g=1}^{G} (GWP_g \times EF_g \times B_{WP,t} \times COMF \times 10^{-3}) \quad (13)$$

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 kilograms to tonnes

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

$$B_{WP,t} = (C_{WP-woody-AB,t-x} + C_{WP-herb,t-x} + C_{WP-DW,t-x} + C_{WP-LI,t-x}) \times (1/CF) \quad (14)$$

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)
$C_{WP\text{-}woody\text{-}AB,t-x}$	=	Average carbon stock in aboveground woody biomass in the project scenario in year t − x (t C/ha)
$C_{WP\text{-}herb,t-x}$	=	Average carbon stock in non-woody biomass in the project scenario in year t − x (t C/ha)
$C_{WP\text{-}DW,t-x}$	=	Average carbon stock in dead wood in the project scenario in year t − x (t C/ha)
$C_{WP\text{-}LI,t-x}$	=	Average carbon stock in litter in the project scenario in year t − x (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
x	=	Length of monitoring period (years)

8.2.2.2 Area-based Quantification of Emissions from Fertilizer Application

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

$$PE_{fert,t} = PE_{Ndirect,t} + PE_{Nindirect,t} \quad (15)$$

Where:

$PE_{fert,t}$	=	Project emissions from nitrogen fertilizer in the monitoring interval ending in year *t* (t CO_2e)
$PE_{Ndirect,t}$	=	Direct nitrous oxide emissions due to fertilizer use in the project scenario in the monitoring interval ending in year *t* (t CO_2e)
$PE_{Nindirect,t}$	=	Indirect nitrous oxide emissions due to fertilizer use in the project scenario in the monitoring interval ending in year *t* (t CO_2e)
t	=	1, 2, 3, ..., *t* years elapsed since the project start date

$$PE_{Ndirect,t} = \left(F_{wp,SN,t} + F_{wp,ON,t}\right) \times EF_{Ndirect} \times \frac{44}{28} \times GWP_g \quad (16)$$

Where:

$PE_{N,direct,t}$	=	Direct nitrous oxide emissions due to fertilizer use in the project scenario in the monitoring period ending in year *t* (t CO_2e)
$F_{wp,SN,t}$	=	Synthetic nitrogen fertilizer applied in the project scenario in the monitoring interval ending in year *t* (t N)
$F_{wp,ON,t}$	=	Organic nitrogen fertilizer applied in the project scenario in the monitoring interval ending in year *t* (t N)
$EF_{Ndirect}$	=	Emission factor for direct nitrous oxide emissions from nitrogen additions due to synthetic fertilizers, organic amendments, and crop residues (t N_2O-N/t N applied)
GWP_g	=	Global warming potential for gas *g* (here, nitrous oxide) (dimensionless)
44/28	=	Ratio of molecular weight of nitrous oxide to nitrogen (unitless)
t	=	1, 2, 3, ..., *t* years elapsed since the project start date

$$\boldsymbol{F_{wp,SN,t} = M_{wp,SF,t} \times NC_{wp,SF,t}} \quad (17)$$

Where:

$F_{wp,SN,t}$	=	Synthetic nitrogen fertilizer applied in the project scenario in the monitoring interval in year *t* (t N)
$M_{wp,SF,t}$	=	Mass of nitrogen-containing synthetic fertilizer applied in the project scenario in the monitoring interval ending in the monitoring period ending in year *t* (t)
$NC_{wp,SF,t}$	=	Nitrogen 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

$$F_{wp,ON,t} = M_{wp,OF,t} \times NC_{wp,OF,t} \quad (18)$$

Where:

$F_{wp,ON,t}$	=	Organic nitrogen fertilizer applied in the project scenario in the monitoring period ending in year *t* (t N)
$M_{wp,OF,t}$	=	Mass of nitrogen-containing organic fertilizer applied in the project scenario in the monitoring interval ending in the monitoring period ending in year *t* (t)
$NC_{wp,OF,t}$	=	Nitrogen 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

$$PE_{Nindirect,t} = Nfert_{wp,volat,t} + Nfert_{wp,leach,t} \tag{19}$$

Where:

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

$$Nfert_{wp,volat,t} = \left[\left(F_{wp,SN,t} \times Frac_{GASF}\right) + \left(F_{wp,ON,t} \times Frac_{GASM}\right)\right] \times EF_{Nvolat} \times \frac{44}{28} \times GWP_g \tag{20}$$

Where:

$Nfert_{wp,volat,t}$	=	Indirect nitrous oxide emissions produced from atmospheric deposition of nitrogen volatilized due to nitrogen fertilizer use in the project scenario in the monitoring interval ending in year *t* (t CO_2e)
$F_{wp,SN,t}$	=	Synthetic nitrogen fertilizer applied in the project scenario in the monitoring interval ending in year *t* (t N)
$Frac_{GASF}$	=	Fraction of all synthetic nitrogen added to soils that volatilizes as ammonia and NO_x (dimensionless)
$F_{wp,ON,t}$	=	Organic nitrogen fertilizer applied in the project scenario in the monitoring interval ending in year *t* (t N)
$Frac_{GASM}$	=	Fraction of all organic nitrogen added to soils that volatilizes as ammonia and NO_x (dimensionless)

EF_{Nvolat}	=	Emission factor for nitrous oxide emissions from atmospheric deposition of nitrogen on soils and water surfaces (t N_2O-N/(t NH_3-N + NO_x-N volatilized))
GWP_g	=	Global warming potential for gas *g* (here, nitrous oxide) (dimensionless)
44/28	=	Ratio of molecular weight of nitrous oxide to nitrogen (unitless)
t	=	1, 2, 3, …, *t* years elapsed since the project start date

$$Nfert_{wp,leach,t} = \left(F_{wp,SN,t} + F_{wp,ON,t}\right) \times Frac_{LEACH} \times EF_{Nleach} \times \frac{44}{28} \times GWP_g \quad (21)$$

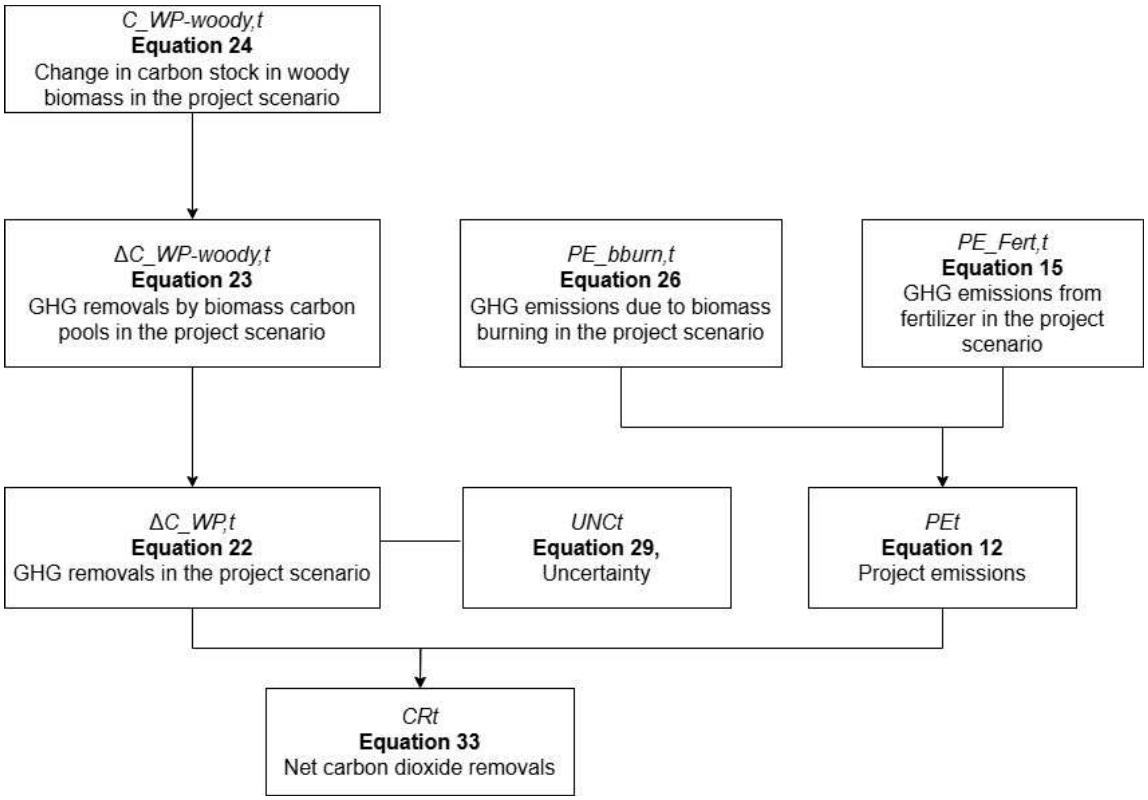
Where:

$Nfert_{wp,leach,t}$	=	Indirect nitrous oxide emissions produced from leaching and runoff of nitrogen, in regions where leaching and runoff occurs, due to nitrogen fertilizer use in the project scenario in the monitoring interval ending in year *t* (t CO_2e)
$F_{wp,SN,t}$	=	Synthetic nitrogen fertilizer applied in the project scenario in the monitoring interval ending in year *t* (t N)
$F_{wp,ON,t}$	=	Organic nitrogen fertilizer applied in the project scenario in the monitoring interval ending in year *t* (t N)
$Frac_{LEACH}$	=	Fraction of synthetic or organic nitrogen 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 nitrous oxide to nitrogen (unitless)
t	=	1, 2, 3, …, *t* years elapsed since the project start date

8.3 Census-based Project Emissions

The calculations of carbon stock changes and project emissions for the census-based approach are summarized in Figure 2.

Figure 2. Summary of calculations for census-based approach



8.3.1 Census-based Project Carbon Stock Changes

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

$$\Delta C_{WP,t} = (\Delta C_{WP-woody,t}) \times \frac{44}{12} \tag{22}$$

Where:

$\Delta C_{WP,t}$	=	Project carbon stock change through year *t* (t CO_2e)
$\Delta C_{WP\text{-}woody,t}$	=	Change in carbon stock in woody biomass 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

Where a project proponent begins measuring carbon stocks after the start date ($t > 0$), the first year of measurement replaces $t = 0$ in all stock change calculations. Between $t = 0$ and $t > 0$, the project's carbon stock change must be assumed to be zero. The project start date remains $t = 0$ for all other purposes, including crediting period determination and baseline setting.

8.3.1.1 Census-based Quantification of Woody Biomass

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

$$\Delta C_{WP-woody,t} = C_{WP-woody,t} \quad (23)$$

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 (*N*) as a scaling factor and adjusting for mortality (M_t) at each monitoring event.

Note – Monitoring of the complete census of planting units is required.

$$C_{WP-woody,t} = N \times (1 - M_t) \times C_{WP-woody-pu\_avg,t} \quad (24)$$

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

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

$$C_{WP-woody-pu\_avg,t} = \frac{1}{n_t} \times \sum_{pu=1}^{n_t} (B_{WP-woody-AB,pu,t} \times (1 + R) \times CF) \quad (25)$$

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/planting unit)
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

8.3.1.2 Census-based Quantification of Non-Woody Biomass

Not applicable (see Table 2).

8.3.1.3 Census-based Quantification of Dead Wood

Not applicable (see Table 2).

8.3.1.4 Census-based Quantification of Litter

Not applicable (see Table 2).

8.3.1.5 Census-based Quantification of Soil Organic Carbon

Not applicable (see Table 2).

8.3.2 Census-based Quantification of Emissions from Biomass Burning and Fertilizer Use

Project emissions resulting from biomass burning and use of fertilizer in the census-based approach are estimated using Equations (26) - (27) and (15) –(21) to respectively.

8.3.2.1 Census-based Quantification of Emissions from Biomass Burning

$PE_{bburn,t}$ is estimated using the following equation:

$$PE_{bburn,t} = \sum_{g=1}^{G}(GWP_g \times EF_g \times B_{WP,t} \times COMF \times 10^{-3}) \tag{26}$$

Where:

$PE_{bburn,t}$	=	Project emissions due to biomass burning in the monitoring interval ending in year t (t CO_2e)
GWP_g	=	Global warming potential for gas g (dimensionless)
EF_g	=	Emission factor for gas g (kg/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.)
$COMF$	=	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 by applying the number of planting units (N) as a scaling factor and adjusting for the percentage of sampled planting units observed to be visibly burned at each monitoring event.

$$B_{WP,t} = N \times \left(\frac{n_{burn,t}}{n_t}\right) \times \left(\frac{1}{n_{t-x}}\right) \times \sum_{pu=1}^{n_t} B_{WP-woody-AB,pu,t-x} \quad (27)$$

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

8.3.2.2 Census-based Quantification of Emissions from Fertilizer Application

Where nitrogen fertilizer is applied due to the project activity, nitrous oxide emissions are estimated under the census-based approach using Equations (15)–(21) in Section 8.2.2.2.

8.4 Leakage Emissions

Emissions from leakage (LK_t) for the area-based approach are accounted using the most recent version of *VMD0054*.

In the census-based quantification approach, LK_t is set equal to zero. The requirement that the ARR project activity maintains pre-project agricultural production levels avoids a change in land use and the planting density threshold avoids any significant displacement of a pre-existing land use due to land use changes such that leakage effects are assumed to be de minimis.

8.5 Uncertainty

Uncertainty associated with sample error is quantified and accounted for. Measurement error is addressed through the application of quality assurance and quality control (QA/QC) procedures detailed in Section 9.

Note – Estimation of emission sources from biomass burning and nitrogen fertilizer apply conservative parameters and associated uncertainty is set at zero.

8.5.1 Area-based Quantification of Uncertainty

Uncertainty in estimating the project accounting boundary (area) is assumed to be zero and is addressed via complete (and accurate) geographic information system (GIS) boundaries of the project or instance areas, and by applying QA/QC procedures specified in the parameter table for *A* (Section 9.1). The performance benchmark is assumed to have zero uncertainty.

Project proponents must use standard methods to estimate uncertainty when calculating changes in carbon stocks. The formula should be appropriate to the type of measurement used and be applied to each carbon pool *p* (representing woody biomass, non-woody biomass, dead wood, litter and SOC) included in the project.

$$UNC_t = \text{MIN}\left(100\%, \text{MAX}\left(0, \left(T \times \frac{\sqrt{SE^2{}_{p,t=0} + SE^2{}_{p,t} - (2 \times \rho \times SE_{p,t=0} \times SE_{p,t}}}{\Delta C}\right) - 0.10\right) \times 100\right) \tag{28}$$

Where:

UNC_t	=	Uncertainty in cumulative removals through year *t* (%)
T	=	Critical value of a student's two-tailed t-distribution for significance level α = 0.1
$SE_{p,t=0}$	=	Standard error of the mean carbon stock estimate at time t = 0 (t CO_2e)
$SE_{p,t}$	=	Standard error of the mean carbon stock estimate at time t (t CO_2e)
ρ	=	Correlation coefficient (rho) between carbon stocks at t = 0 and t (used only for permanent plots; term is set to zero for independent measurements between t = 0 and t)
ΔC	=	Mean change in carbon stocks between t = 0 and t (t CO_2e)

Note – Equation(28) above is applicable to projects that maintain their inventory method throughout the project crediting period. Where projects switch approaches (e.g., independent inventories between t = 0 and t = 5, and then permanent plots are used from t = 5 onwards), the combined uncertainty between periods must be estimated using the steps shown in Appendix 3.

8.5.2 Census-based Quantification of Uncertainty

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

Uncertainty when estimating changes in carbon stocks is calculated by propagating errors associated with estimates of included pools as follows:

$$UNC_t = \text{MIN}\left(100\%, \text{MAX}\left(0, \left(T \times \frac{\sqrt{SE^2_{p,t} + (C_{total,t} \times \frac{U_{M,t}}{100})^2}}{C_{total,t}}\right) - 0.10\right) \times 100\right) \tag{29}$$

Where:

UNC_t	=	Uncertainty in cumulative removals through year *t* (%)
$U_{M,t}$	=	Percentage uncertainty in population size adjusted for mortality in the project scenario in year *t* (%)
t	=	1, 2, 3, ..., *t* years elapsed since the project start date
T	=	Critical value of a student's two-tailed t distribution for significance level α = 0.1
$SE_{p,t}$	=	Standard error of average woody biomass per planting unit in pool *p* (here restricted to woody biomass CWP-biomass) in the project scenario at time *t* (t CO_2e)
$C_{total,t}$	=	Total carbon stock at time *t*, calculated using Equation (29) (t CO_2e)

$$C_{total,t} = N \times (1 - M_t) \times \bar{C}_{pu,t} \tag{30}$$

Where:

N	=	Initial population size (number of planting units)
M_t	=	Mortality through year *t* (%)
$\bar{C}_{pu,t}$	=	Mean carbon per planting unit at time *t* (t CO_2e)

$$U_{M,t} = T \times \sqrt{\frac{M_t \times (1 - M_t)}{n_t - 1}} \times \frac{1}{1 - M_t} \tag{31}$$

Where:

$U_{M,t}$	=	Percentage uncertainty in population size adjusted for mortality in the project scenario in year *t* (%)
T	=	Critical value of a student's two-tailed t distribution for significance level α = 0.1
M_t	=	Mortality through year *t* (%)
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% confidence interval exceeds 100% of the carbon dioxide removal estimate.

8.6 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 five-year interval). The total removals for the period are then divided by the number of years in the monitoring interval (Equation 34) to calculate an annualized value, ensuring equal carbon removals (CR_t) are assigned to each year within the monitoring interval.

8.6.1 Area-based Quantification of Estimated Carbon Dioxide Removals

$$CR_t = \left(MIN\left(\Delta C_{WP,t}, \Delta C_{WP,t} \times (1 - PB_t)\right) \times (1 - UNC_t)\right) - PE_t - LK_t - \left(\left(MIN\left(\Delta C_{WP,t-x}, \Delta C_{WP,t-x} \times (1 - PB_{t-x})\right) \times (1 - UNC_{t-x})\right) - PE_{t-x} - LK_{t-x}\right) \tag{32}$$

Where:

CR_t	=	Carbon dioxide removals from the project activity in the monitoring interval ending in year *t* (t CO_2e)
$\Delta C_{WP,t}$	=	Project carbon stock change through year *t* (t CO_2e)
PB_t	=	Performance benchmark for the monitoring interval ending in year *t* (%)
LK_t	=	Leakage through year *t* (t CO_2e)
PE_t	=	Project emissions from biomass burning and fertilizer use in year *t* (t CO_2e)
UNC_t	=	Uncertainty in cumulative removals through year *t* (%)

8.6.2 Census-based Quantification of Estimated Carbon Dioxide Removals

Carbon dioxide removals using census-based quantification are calculated with carbon stock changes in the baseline scenario (see Section 6) and leakage (see Section 8.4) implicitly set equal to zero.

$$CR_t = \left(\Delta C_{WP,t} \times (1 - UNC_t)\right) - \left(\Delta C_{WP,t-x} \times (1 - UNC_{t-x})\right) - PE_t \tag{33}$$

Where:

CR_t	=	Carbon dioxide removals from the project activity over the monitoring interval ending in year *t* (t CO_2e)
$\Delta C_{WP,t}$	=	Project carbon stock change through year *t* (t CO_2e)
PE_t	=	Project emissions from biomass burning and fertilizer use in year *t* (t CO_2e)
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 conform to the most recent version of the *VCS Standard* for applying the long-term average (LTA) GHG benefit as an upper limit on calculated carbon dioxide removals.

8.6.3 Annualized Carbon Dioxide Removals

To calculate annualized carbon dioxide removals ($CR_{annualized}$), divide the total removals (CR_t) in the monitoring interval by the length of the monitoring interval (x):

$$CR_{annualized} = \frac{CR_t}{x} \tag{34}$$

Where:

$CR_{annualized}$	=	Annualized carbon dioxide removals (t CO_2e/year)
CR_t	=	Carbon dioxide removals from the project activity over monitoring interval t (t CO_2e)
x	=	Length of the monitoring period (years)

8.7 Area-based and Census-based Ex-Ante Estimation

The project description must include an ex-ante estimation of carbon dioxide removals to demonstrate the expected difference between modeled performance of the project and the projected “no change” baseline (census-based only) or the forecasted performance benchmark (area-based only). The ex-ante estimation must meet the following requirements:

1) At validation, ex-ante estimates must be made for the length of the crediting period. Projected changes in biomass must be based on growth and yield models constructed with data and parameters that conservatively represent the project activity.
2) Any harvest regimes or forest management activities must be incorporated when modeling the project scenario.
3) A minimum uncertainty deduction of 10% must be applied. An uncertainty deduction greater than 10% may be selected by the project proponent if they wish to be more conservative.
4) The ex-ante estimate of removals is derived as follows:
    a) For the area-based approach: Use Equation (1), with parameter $\Delta C_{WP\text{-}biomass,t}$ from modeled growth and yield values: the output of the growth and yield model must provide an estimate in t C, which provides the value for $\Delta C_{WP\text{-}biomass,t}$ used in Equation (1).
    b) For the census-based approach: Use Equation (22) with parameter $\Delta C_{WP\text{-}woody,t}$ from modeled growth and yield values: the output of the growth and yield model must provide an estimate in t C, which provides the value for $\Delta C_{WP\text{-}woody,t}$ used in Equation (22)
5) The ex-ante baseline is set to zero where the project uses the census-based approach.

6) Projects using the area-based approach forecast a performance benchmark, which is determined by applying the procedures outlined in Appendix 1 with parameters estimated as follows:

   a) Expected changes in biomass (t C) over the crediting period are first estimated using a growth and yield model. A regression model based on published studies or validation datasets is then used to convert these biomass estimates into stocking index values to derive $\Delta SI_{wp,t}$.

   b) The change in stocking index for control plots may be estimated by assuming a linear trend between $t = -10$ and $t = 0$, using the slope of that interval as the basis for projecting performance across the crediting period to derive the ex-ante slope for $\Delta SI_{control,t}$.

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

9 MONITORING

9.1 Data and Parameters Available at Validation

Data/Parameter	*A*
Data unit	ha
Description	Project area
Equations	(3), (5), (7), (9), (11)
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 coverage, 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 (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), (25)
Source of data	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:

	1) Values specific to the forest type within the same ecoregion (defined at the biome level following Olson et al. 2001[14]) or Holdridge life-zone[15] as the region in which the project is located 2) Global values specific to the forest type (e.g., from Table 4.4 in Chapter 4, Volume 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: 3) 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 4) Global values specific to the species, genus, or family (e.g., from Table 4.4 in Chapter 4, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*) 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
Comments	None

Data/Parameter	*CF*
Data unit	t C/t d.m.
Description	Carbon fraction of dry biomass
Equations	(6), (8), (10), (13), (25)

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

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

Source of data	*2006 IPCC 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 Standard*.
Purpose of data	Calculation of project emissions
Comments	None

Data/Parameter	*COMF*
Data unit	dimensionless
Description	Combustion factor
Equations	(12), (26)
Source of data	Default mean values in Table 2.6 in Chapter 2, Volume 4 of *2019 Refinement to the 2006 IPCC 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 Standard*.
Purpose of data	Calculation of project emissions
Comments	None

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

Equations	(12), (26)
Source of data	Table 2.2 in Chapter 2, Volume 2 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (and in the same document, 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 Standard*.
Purpose of data	Calculation of project emissions
Comments	None

Data/Parameter	GWP_g
Data unit	dimensionless
Description	Global warming potential for gas *g*
Equations	(13), (16), (20), (21), (26)
Source of data	Default factor from the most recent 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 Standard.
Purpose of data	Calculation of project emissions
Comments	None

Data/Parameter	$EF_{Ndirect}$
Data unit	t N_2O-N/t N applied

Description	Emission factor for direct nitrous oxide emissions from nitrogen additions due to synthetic fertilizers, organic amendments, and crop residues
Equations	(16)
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 Standard*.
Purpose of data	Calculation of project emissions
Comments	Emission factors applicable to nitrogen additions from mineral fertilizers, organic amendments, and crop residues

Data/Parameter	$Frac_{GASF}$
Data unit	dimensionless
Description	Fraction of all synthetic nitrogen added to soils that volatilizes as ammonia and NO_x
Equations	(20)
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 Standard*.
Purpose of data	Calculation of project emissions
Comments	None

Data/Parameter	$Frac_{GASM}$
Data unit	dimensionless
Description	Fraction of all organic nitrogen added to soils that volatilizes as ammonia and NO_x
Equations	(20)
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	0.21
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the *VCS Standard*.
Purpose of data	Calculation of project emissions
Comments	None

Data/Parameter	EF_{Nvolat}
Data unit	t N_2O-N/(t NH_3-N + NO_x-N volatilized)
Description	Emission factor for nitrous oxide emissions from atmospheric deposition of nitrogen on soils and water surfaces
Equations	(20)
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 Standard*.
Purpose of data	Calculation of project emissions
Comments	None

Data/Parameter	$Frac_{LEACH}$
Data unit	dimensionless
Description	Fraction of synthetic or organic nitrogen added to soils that is lost through leaching and runoff, in regions where leaching and runoff occurs
Equations	(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 Standard*.
Purpose of data	Calculation of project emissions
Comments	None

Data/Parameter	EF_{Nleach}
Data unit	t N_2O-N/t N leached and runoff
Description	Emission factor for nitrous oxide emissions from leaching and runoff
Equations	(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	0.011
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the *VCS Standard*.
Purpose of data	Calculation of project emissions

Comments	None

Data/Parameter	*N*
Data unit	integer
Description	Initial population size (number of planting units)
Equations	(24), (27), (30)
Source of data	Complete census/enumeration
Value applied	The original population size (*N*) is established via an initial complete census of all planting units. For each planting unit, the following must be recorded in the project description: 1) Unique ID 2) Geo-referenced point of the location 3) Year planted 4) 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 (census-based quantification)
Comments	Planting units must be clearly defined (e.g., tree, shrub, bamboo clump) and identifiable in the field.

9.2 Data and Parameters Monitored

Data/Parameter	$C_{WP\text{-}woody\text{-}AB,t}$
Data unit	t C/ha
Description	Average carbon stock in aboveground woody biomass in the project scenario in year *t*
Equations	(4) (13)

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 may be augmented using double or two-phase sampling approaches (e.g., sampling probability proportional to prediction (3P) or ratio sampling). These approaches must include: 1) a complete census of an auxiliary variable (e.g., stocking index, see Appendix 1). 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 QA/QC procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection). c) apply fixed size thresholds to 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 following Olson et al. 2001) or Holdridge (1967) life-zone as the region in which the project is located. 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.

	iv) Global equations specific to the species, genus, or family 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., M. J. Ducey, T. W. Beers, and B. Husch. 2016. *Forest Mensuration*. John Wiley & Sons. Avery, T. E., and H. E. Burkhart. 2015. *Forest Measurements*. Waveland Press. Measurement and sampling 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 (area-based quantification)
Calculation method	Calculated as the average of sample measurements
Comments	*VT0005 Tool for Measuring Aboveground Live Forest Biomass Using Remote Sensing* does not apply.

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	(6)
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. 2) ensure accuracy through adherence to best practices and QA/QC procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection). 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	See "Description of measurement methods and procedures to be applied."
Purpose of data	Calculation of project emissions (area-based quantification)
Calculation method	Calculated as the average of sample measurements
Comments	Where subsampling is employed to determine a dry-to-wet mass ratio, uncertainty is calculated by treating the sample as a double sample.

Data/Parameter	$B_{SDW,t}$
Data unit	t d.m./ha
Description	Average biomass of standing dead wood in year *t*
Equations	(8)
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 QA/QC procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection). 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 following Olson et al. 2001) or Holdridge (1967) life-zone as the region in which the project is located. 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. d) Global equations specific to the species, genus, or family 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. 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., M. J. Ducey, T. W. Beers, and B. Husch. 2016. *Forest Mensuration*. John Wiley & Sons. Avery, T. E., and H. E. Burkhart. 2015. *Forest Measurements*. Waveland Press. Measurement and sampling 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 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 (area-based quantification)
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	(8)
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 another unbiased 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 QA/QC procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection). 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 (area-based quantification)
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	(10)
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 ºC 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 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 handbooks, such as those published by FAO and available on the FAO Soils Portal[16] or from the IPCC GPG LULUCF, is recommended.
Purpose of data	Calculation of project emissions (area-based quantification)
Calculation method	Calculated as the average of sample measurements
Comments	Where subsampling is employed to determine a dry-to-green weight ratio, uncertainty is calculated by treating the sample as a double sample.

Data/Parameter	$C_{WP\text{-}SOC,t}$
Data unit	t C/ha
Description	Average soil organic carbon (SOC) stock in the project scenario in year t
Equations	(11)
Source of data	Field measurements
Description of measurement methods and procedures to be applied	Measured SOC must be determined from samples collected from sample plots located within the project area. Stratification must be employed to improve precision. The sample design should be held constant across all monitoring and verification events to ensure accuracy and conservativeness of carbon stock changes. Where a change in sample design is needed, documentation of the change and the reason for the change must be provided to Verra and the validation/verification body. All organic material (e.g., living plants, litter) must be cleared from the surface prior to soil sampling. Soil must be sampled to a minimum depth

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

	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. 2) ensure accuracy through employment of 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): 275–88. Petersen, R. G., and L. D. Calvin. 1986. "Sampling." In *Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods*, edited by A. Klute. 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 and Hauser 2013). Determination of percentage SOC must follow established laboratory procedures, such as those found in: Nelson, D. W., and L. E. Sommers. 1996. "Total carbon, organic carbon, and organic matter." In *Methods of Soil Analysis. Part 3 Chemical Methods*, edited by A. L. Page et al. 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): 1) occurs no more than once during the project crediting period (i.e., at site preparation); or

	2) 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 handbooks, such as those published by FAO and available on the FAO Soils Portal[17] or from IPCC. 2003. *GPG LULUCF*, is recommended.
Purpose of data	Calculation of project emissions (area-based quantification)
Calculation method	Calculated as the average of sample measurements
Comments	None

Data/Parameter	$A_{burn,t}$
Data unit	ha
Description	Area burned in the monitoring interval ending in year *t*
Equations	(13)
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 (area-based quantification)
Calculation method	Calculated using GIS
Comments	None

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

Data/Parameter	$M_{wp,SF,t}$ $M_{wp,OF,t}$
Data unit	tonnes
Description	Mass of nitrogen-containing synthetic fertilizer applied in the project scenario in the monitoring interval ending in year *t.* Mass of nitrogen-containing organic fertilizer applied in the project scenario in the monitoring interval ending in year *t*
Equations	(17) (18)
Source of data	Mass of 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
Calculation method	N/A
Comments	None

Data/Parameter	$NC_{wp,SF,t}$
Data unit	t N/t fertilizer
Description	Nitrogen content of synthetic fertilizer applied in the project scenario in year *t*
Equations	(17)

Source of data	Nitrogen content is determined following fertilizer manufacturer's specifications.
Description of measurement methods and procedures to be applied	Not directly measured. Recorded from fertilizer manufacturer's specifications and evidenced in management records, receipts, or invoices.
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
Calculation method	N/A
Comments	None

Data/Parameter	$NC_{wp,OF,t}$
Data unit	t N/t fertilizer
Description	Nitrogen content of organic fertilizer applied in the project scenario in year *t*
Equations	(18)
Source of data	Published or peer-reviewed data must be used, with preference for more recent data from the country in which the project is located.
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

Calculation method	N/A
Comments	None

Data/Parameter	n_t
Data unit	integer
Description	number of planting units sampled in year t
Equations	(25), (27), (31)
Source of data	Sampling
Value applied	The number of samples selected from the original population size (*N*) is established via randomized sampling of the initial complete census of all planting units. For each sampled planting unit, the following must be recorded in the monitoring report: 1) Unique ID 2) Geo-referenced point of the location 3) Year planted 4) 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 (census-based quantification)
Comments	Planting units must be clearly defined (e.g., tree, shrub, bamboo clump) and identifiable in the field.

Data/Parameter	M_t
Data unit	%
Description	Mortality through year *t*
Equations	(24), (30), (31)

Source of data	Complete re-enumeration or sampling
Description of measurement methods and procedures to be applied	Where 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) relocating the planting unit is not possible.
Frequency of monitoring/recording	Every five 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 (census-based quantification)
Calculation method	Calculated as a percentage of a sample or census
Comments	None

Data/Parameter	$B_{WP\text{-}woody\text{-}AB,pu,t}$
Data unit	t d.m.
Description	Estimated biomass stock in aboveground woody biomass in sampled planting unit *pu* in the project scenario in year *t*
Equations	(25) (27)
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. Sampling approaches may be augmented using double or two-phase sampling approaches (e.g., sampling probability proportional to prediction (3P) or ratio 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. 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 QA/QC procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection). 3) apply fixed size thresholds to 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 b) Global equations specific to the species, genus, or family 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., M. J. Ducey, T. W. Beers, and B. Husch. 2016. *Forest Mensuration*. John Wiley & Sons. Avery, T. E., and H. E. Burkhart. 2015. *Forest Measurements*. Waveland Press. Measurement and sampling 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 (census-based quantification)
Calculation method	Calculated as the average of sample measurements
Comments	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	$n_{burn,t}$
Data unit	integer
Description	Number of sampled planting units recorded as burned in the monitoring interval ending in year *t*
Equations	(27)
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 (census-based quantification)
Calculation method	N/A
Comments	None

Data/Parameter	$SE_{p,t}$
Data unit	tCO2e

Description	Standard error of the mean carbon stock estimate for carbon pool *p* in the project scenario in year *t*
Equations	(28) (29)
Source of data	Calculations from sampled field measurements
Description of measurement methods and procedures to be applied	Standard error is calculated as the standard deviation of sample values for the relevant carbon pool *p* divided by the square root of the number of plots (or planting units, in the census-based approach). Where double sampling is used, SE is calculated as the root mean squared error of the regression (for ratio or regression estimators) scaled to the sample size. The estimate must be derived from representative, unbiased sampling.
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	Field protocols must include procedures for plot selection, consistent measurement techniques, and data recording to minimize measurement error. QA/QC procedures should be documented in standard operating procedures and must include error checking and outlier detection in the sample data.
Purpose of data	Used in the calculation of project-level uncertainty for both the area and census-based approaches
Calculation method	SE is calculated using unbiased estimators appropriate to the sample design (e.g., simple random, stratified, or double sampling). Refer to Cochran (1977) and Appendix 3 for applicable formulas.
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, pool *p* includes woody biomass only.

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 (i.e., area-based, census-based, or a combination of both). Where using the census-based approach, the plan must clearly define the planting unit. If using the area-based approach, see procedures 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 that are applied in calculations identified.

6) Anticipated frequency of monitoring for each variable

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

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

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

10) Specific schedule and procedures for periodically acquiring, archiving, and processing remote sensing data to derive stocking indices

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 used 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., and H. E. Burkhart. 2015. *Forest Measurements*. Waveland Press.

Bird, D. N., N. Pena, H. Schwaiger, and G. Zanchi. 2010. *Review of Existing Methods for Carbon Accounting*. CIFOR Occasional Paper (54).

Cline, M. G. 1944. "Principles of soil sampling." *Soil Science* 58 (4): 275–88.

Cochran, W. G. 1977. *Sampling Techniques*. John Wiley & Sons.

Ducey, M. J., M. S. Williams, J. H. Gove, S. Roberge, and R. S. Kenning. 2013. "Distance-limited perpendicular distance sampling for coarse woody debris: Theory and field results." *Forestry* 86 (1): 119–28. https://doi.org/10.1093/forestry/cps059

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

Harmon, M. E., C. W. Woodall, B. Fasth, J. Sexton, and M. Yatkov. 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. Data available at: http://iridl.ldeo.columbia.edu/SOURCES/.ECOSYSTEMS/.Holdridge/present+.life-zone/downloadsGeoTiff.html

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., M. J. Ducey, T. W. Beers, and B. Husch. 2016. *Forest Mensuration*. John Wiley & Sons.

Mathur, A., A. P. Chikkatur, and A. D. Sagar. 2007. "Past as prologue: An innovation-diffusion approach to additionality." *Climate Policy* 7 (3): 230–9. https://doi.org/10.1080/14693062.2007.9685651

Nelson, D. W., and L. E. Sommers. 1996. "Total carbon, organic carbon, and organic matter." In *Methods of Soil Analysis. Part 3 Chemical Methods*, edited by A. L. Page, P. A. Helmke, R. H. Loeppert, et al. American Society of Agronomy and Soil Science Society of America. (pp. 961–1010).

Olson, D. M., E. Dinerstein, E. D. Wikramanayake, et al. 2001. “Terrestrial ecoregions of the world: A new map of life on earth. A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity.” *BioScience* 51 (11): 933–8. https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2

Petersen, R. G., and L. D. Calvin. 1986. “Sampling.” In *Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods*, edited by A. Klute. 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*. US Environmental Protection Agency.

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

Van Wagner, C. E. 1968. “The line intersect method in forest fuel sampling.” *Forest Science* 14 (1): 20–6. https://doi.org/10.1093/forestscience/14.1.20

Warren, W. G., and P. F Olsen. 1964. “A line intersect technique for assessing logging waste.” *Forest Science* 10 (3): 267–76. https://doi.org/10.1093/forestscience/10.3.267

Wendt, J. W., and S. Hauser. 2013. “An equivalent soil mass procedure for monitoring soil organic carbon in multiple soil layers.” *European Journal of Soil Science* 64 (1): 58–65. https://doi.org/10.1111/ejss.12002

Williams, M. S., and J. H. Gove. 2003. “Perpendicular distance sampling: An alternative method for sampling downed coarse woody debris.” *Canadian Journal of Forest Research* 33 (8): 1564–79. https://doi.org/10.1139/x03-056

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

APPENDIX 1: PERFORMANCE METHOD

A1.1 Applicability Conditions

This appendix is applicable where all the following conditions are met:

1) The project meets all applicability conditions detailed in Section 4 of this methodology.
2) The project activities will produce vegetative cover allowing for clear spatial delineation of the project area.
3) The project's performance benchmark is updated at each verification or every five years, whichever comes first.

A1.2 Baseline Scenario

The baseline scenario is represented by the business-as-usual growth of carbon stocks in aboveground biomass, as observed on representative remotely sensed control plots located outside of any registered AFOLU project area. 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 plots based on similar biophysical, social, and political conditions, and historic stock trends (see Section A1.4). SI in control plots is detected using remote sensing and does 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 – All project and control plots referenced in this appendix are remotely sensed and will therefore be referred to as "project plots" and "control plots" from here onwards in Appendix 1.

A1.3 Performance Benchmark

The performance benchmark is determined by comparing the average rate of increase in the stocking index (SI) between project and control plots in Equation (A8). Equation (A7) demonstrates common practice additionality. 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 Section A1.4). The project slope is derived from the growth and yield curve procedure provided in ex-ante calculations (see Section 8.7).

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 removals is treated in Section 8 and is dependent on direct field measurement.

A1.4 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. The location of all stocking index project and control plots must also be included in the project description. All of the following steps must be fully documented as part of the monitoring plan for project and control plots, as described in Section 9.3. Description of the Monitoring Plan.

Step 1: Select Project Plots

The following must be performed for each annual cohort separately.

1) Divide the entire project annual cohort area into equal-sized, contiguous, non-overlapping units (project plots) with area ranging from 0.01 hectares (10 × 10 m) to 10 hectares. At least 75% 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 across the project area using random sampling.

Note – If the project is stratified or is a grouped project where new instances are added in subsequent years, individual strata may contain fewer than 30 plots, provided the total sample size is at least 30 and each stratum is used to establish a separate performance benchmark.

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 the criteria listed 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 a resolution no coarser than 30 × 30 meters and must match or be finer than the resolution of the project plots used as units of analysis (see Step 1(1) above).

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

Matching Criteria	Description
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.
Policy environment	The donor pool area must exclude any areas of the jurisdictional boundary (defined above) with presence/absence of any operating national or subnational government-funded policy/program providing incentives for tree planting that differs from that in the project area (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 and control plots:

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

Quantify historic and initial conditions of *SI* via a time series analysis for a representative sample of control and project plots (Table A2). For each control plot, calculate a multivariate distance metric relative to each project plot, *MD* (e.g., Euclidean distance, Mahalanobis distance), across the vector of covariates. The vector of covariates must include stocking indices from at least three time points as described in Table A2.

Table A2. Required covariates for matching control plots to project plots (detailed guidance on each covariate provided in Section A1.5)

Matching covariate	Description
$SI_{t=0}$, $SI_{t=-10}$, etc.	Covariates used for evaluating the multivariate distance between control and project plots must include stocking indices from three or more time points during the historic period. At minimum, stocking indices from each of the following periods must be selected: • Between $t = -10$ and $t = -8$ • Between $t = -8$ and $t = -1$ • At $t = 0$

3) Match control and project 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, that sum to 1, proportional to the inverse of the multivariate distance metric value.

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

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 stocking index covariate, *u*, calculate the standardized difference of means (*SDM*) as follows:

$$SDM = \left|\bar{v}_{wp,\mathrm{u}} - \bar{v}_{bsl,\mathrm{u}}\right| \Big/ \sqrt{\left(\frac{\sigma^2_{wp,v} + \sigma^2_{bsl,v}}{2}\right)} \quad \text{(A2)}$$

Where:

SDM	=	Standardized difference of means
$\overline{V}_{wp,u}$	=	Mean value of covariate *u* in the population of project plots
$\overline{V}_{bsl,u}$	=	Mean value of weighted sums of covariate *u* in the population of matched sets of control plots
$\sigma^2_{wp,v}$	=	Sample variance of covariate *v* in the population of project plots
$\sigma^2_{bsl,v}$	=	Weighted sample variance of covariate *v* 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 Universal Transverse Mercator (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:

1) progressively expanding the radius of the donor pool in 100 km increments, and/or
2) 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 the 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:

1) 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
2) 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 two, annual time steps: t and t = 0. Observations from all previous verifications must also be included.

To be included in the dataset, *SI* values must be available at time t for 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 must not be used in the derivation of $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$ at time t. A minimum of n = 30 project plots must be obtained for a representative sample of the area.

The rate of increase in stocking index in the control ($\Delta SI_{control,t}$) and project ($\Delta SI_{wp,t}$) plots is calculated in Equations (A5) and (A6) as the slope of the weighted least squares regression (WSLR) of the accumulated time series of *SI* values for the respective population of plots.

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

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

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 with values assessed at time *t*

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

$$W_{wp,i,t} = \frac{1}{\sum_{t=0}^{t} n\_rs_t} \quad \text{(A4)}$$

Where:

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

WSLR is used to derive $\Delta SI_{control,t}$ in Equation (A5) and $\Delta SI_{wp,t}$ in Equation (A6). These equations estimate the slope of stocking index over time by calculating the weighted covariance between time and stocking index, divided by the weighted variance of time.

$$\Delta SI_{control,t} = \frac{\sum_{i,j}\left(W_{control,i,j,t} \times t \times SI_{control,i,j,t}\right) - \frac{\sum_{i,j}(W_{control,i,j,t} \times t) \times \sum_{i,j}(W_{control,i,j,t} \times SI_{control,i,j,t})}{\sum_{i,j}\left(W_{control,i,j,t}\right)}}{\sum_{i,j}\left(W_{control,i,j,t} \times t^2\right) - \frac{\left(\sum_{i,j}(W_{control,i,j,t} \times t)\right)^2}{\sum_{i,j}\left(W_{control,i,j,t}\right)}} \quad \text{(A5)}$$

Where:

$\Delta SI_{control,t}$	=	Slope of stocking index of control plots over time
$W_{control,i,j,t}$	=	Weight of control plot *j* matched to project plot *i*, at time *t*
$SI_{control,i,j,t}$	=	Stocking index of control plot *j* matched to project plot *i*, at time *t*
t	=	1, 2, 3, …, *t* years elapsed since the project start date

In Equation (A5), weights of control plots $W_{control,i,j,t}$ are calculated using Equation (A1), which reflects the relative representativeness of each control plot, and Equation (A3), which adjusts these weights over time based on the cumulative number of matched control plots. These weights are applied in the regression to reflect confidence in the quality of observation matching, based on pre-project conditions, and moderate the relative influence of each individual control plot observation as the data set grows over time.

Note – Unlike some WLSR applications, these weights are not derived from estimation of residual error variance.

$$\Delta SI_{wp,t} = \frac{\sum_{i}\left(W_{wp,i,t} \times t \times SI_{wp,i,t}\right) - \frac{\sum_{i}(W_{wp,i,t} \times t) \times \sum_{i}(W_{wp,i,t} \times SI_{wp,i,t})}{\sum_{i}\left(W_{wp,i,t}\right)}}{\sum_{i}(W_{wp,i,t} \times t^2) - \frac{\left(\sum_{i}\left(W_{wp,i,t} \times t\right)\right)^2}{\sum_{i}\left(W_{wp,i,t}\right)}} \quad \text{(A6)}$$

Where:

$\Delta SI_{wp,t}$	=	Slope of stocking index of project plots over time
$W_{wp,i,t}$	=	Weight of project plot *i* at time *t*
$SI_{wp,i,t}$	=	Stocking index of project plot i at time *t*
t	=	1, 2, 3, …, *t* years elapsed since the project start date

In Equation (A6), weights of project plots $W_{wp,i,t}$ are calculated using the assigned weights from Equation (A4), which scale the cumulative number of project plots included in the analysis from $t = 0$ to time *t*. This ensures that all project plot observations are weighted equally while normalizing their relative influence as the number of observations grows over time.

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

$$Z = \frac{\Delta SI_{wp,t} - \Delta SI_{control,t}}{\sqrt{SE^2_{\Delta SI\_wp,t} + SE^2_{\Delta SI\_control,t}}} \quad \text{(A7)}$$

Where:

Z	=	Z value (unitless)
$\Delta SI_{control,t}$	=	Weighted average annual increase (slope) in stocking index *SI* in control plots through time *t*
$\Delta SI_{wp,t}$	=	Weighted 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 that harvest as part of the project activity must reference the most recent version of the *VCS Standard* and follow the requirement for applying a long-term average.

Step 6: Derive Performance Benchmark

The performance benchmark is calculated by either pathway (a) or (b) as follows:

a) Where parameters $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$ are not significantly different ($|Z| < 1.96$, see above), PB_t is set equal to 1 and Equation (A8) is not applicable.

b) Where parameters $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$ are significantly different ($|Z| \geq 1.96$, see above), calculate the performance benchmark according to Equation (A8).

$$PB_t = \Delta SI_{control,t} \times \frac{1}{\Delta SI_{wp,t}} \quad \text{(A8)}$$

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 year *t*
$\Delta SI_{wp,t}$	=	Average annual increase in stocking index, *SI*, in project plots through year *t*
t	=	1, 2, 3, …, *t* years elapsed since the project start date

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 (A8).

A1.5 Data and Parameters Monitored

Data/Parameter	$SI_{control,t}$ $SI_{wp,t}$
Data unit	unspecified
Description	Stocking index in scenario (control plot *j* or project plot *i*) at time *t*
Equations	(A5) (A6)
Source of data	*SI* is an unspecified remote sensing metric with demonstrated correlation with terrestrial aboveground carbon stocks (e.g., normalized difference fraction index[18] 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). The target period should coincide with minimal seasonal phenological variation and where passive remote sensors are employed this should coincide with months of lowest cloud cover.
Description of measurement methods and procedures to be applied	Spatial scale/mapping unit: Divide the entire project area into equal-sized polygons from 0.01 hectares (10 × 10 m) to 10 hectares in area. At least 75% of each polygon must be located within the project area boundary. Project plots may be represented by individual pixels or aggregates of pixels.
Frequency of monitoring/recording	At least annually
QA/QC procedures to be applied	The remote sensing metric applied must be: 1) significantly correlated with terrestrial carbon stocks, at least with aboveground biomass, as previously demonstrated in published or peer-reviewed studies; or 2) validated with direct measurements from the project region (collected from within the project ecoregion; ecoregion defined at the biome level following Olson et al. 2001). Processing and analysis of remote sensing data must apply established best practices, such as those found in:

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

	Global Forest Observations Initiative. 2020. *Integration of Remote-Sensing and Ground-based Observations for Estimation of Emissions and Removals of Greenhouse Gases in Forests: Methods and Guidance from the Global Forest Observations Initiative, edition 3.0*. U.N. Food and Agriculture Organization.[19] Mitchell, A. L., A. Rosenqvist, and B. Mora. 2017. "Current remote sensing approaches to monitoring forest degradation in support of countries measurement, reporting and verification (MRV) systems for REDD+." *Carbon Balance and Management* 12: 9. https://doi.org/10.1186/s13021-017-0078-9 In edition 3.0, GFOI endorses using biomass and biomass change maps "as a source of auxiliary data for increasing the precision of estimates of emissions, removals and/or emissions and removals factors based on ground plot reference data" as well as indicating that "[i]n the absence of ground data, global biomass maps can be used as sources of reference data for estimating biomass." (in Chapter 4.3.1.2).
Purpose of data	Selection of control plots and derivation of performance benchmark for the area-based approach
Calculation method	Dependent on remote sensing metric used
Comments	*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 more accurate remote sensing metrics become available over time, the remote sensing metric used for monitoring *SI* ex-post may be changed when all the following apply: a) The new metric offers equivalent or better accuracy (in terms of terrestrial carbon stocks). b) The new metric can be harmonized with the previous metric, applying procedures from peer-reviewed literature[20] to ensure data continuity and remove sources of misalignment (e.g., geometric, radiometric, and/or spectral artifacts) introduced by the new metric. c) 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

[19] Available at: https://www.fs.usda.gov/research/treesearch/61714

[20] For example https://www.usgs.gov/landsat-missions

	within an overlap interval of at least two years, or as prescribed by the procedure. The location of all stocking index project and control plots must be included in the project description.

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

This appendix outlines a stepwise procedure for determining the significance of decreases in optional carbon pools and GHG emission sources (E_s). All E_s may be deemed de minimis and excluded from quantification if their combined impact (in t CO_2e) is less than 5% of the total amount of carbon removal expected from the project, see Step 1, Equation (A9). Where the combined significance of optional pools and emissions sources is greater than 5% proceed to Step 2 Equation (A10) to determine which individual carbon pools and GHG emissions sources must be included.

Note: – Leakage is excluded from this calculation as it must be accounted for regardless of the amount of quantified leakage emissions.

Step 1: Determine Combined Significance of E_s

$$CSR = \frac{\sum E_s}{CR} \tag{A9}$$

CSR	=	Combined significance ratio
CR	=	Total carbon dioxide removals expected from the project (tCO_2e)
E_s	=	Project emissions and decreases in optional carbon pools (tCO_2e)
s	=	1, 2, 3, …, *S* sources of project GHG emissions and decreases in carbon pools

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

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

Step 2: Determine Significance of Individual E_s

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

$$RC_{Es} = \frac{E_s}{\sum E_s} \tag{A10}$$

Where:

RC_{Es}	=	Relative contribution of each source *s* to the sum of project and leakage GHG emissions
E_s	=	GHG project emissions, and decreases in carbon pools (tCO_2e)
s	=	1, 2, 3, …, S sources of project GHG emissions (excluding leakage) and decreases in carbon pools

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

2) Add the sources starting from the largest. Stop when the cumulative total equals or exceeds 95%.

3) Include all the sources that add up to, or exceed, 95%.

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

APPENDIX 3: UNCERTAINTY EQUATIONS FOR CHANGING SAMPLING APPROACHES

Section 8.5.1 shows how uncertainty deductions under the area-based approach are calculated when projects use one inventory approach across the entire crediting period. This appendix provides the stepwise approach for calculating the uncertainty deduction (UNC_t) in the area-based approach when a project proponent switches sampling approaches, for example where a project proponent uses independent measurements (e.g., temporary plots) between t = 0 and an intermediate time t_1, and then switches to permanent plots (i.e., dependent measurements) from t_1 to any future time t.

Step 1: Quantify the Standard Error for the First Inventory Period

For the interval between t = 0 and t_1, using independent plots (uncorrelated errors):

$$SE_{\Delta C,t0 \rightarrow t1} = \sqrt{SE_{t=0}^2 + SE_{t1}^2} \tag{A11}$$

Where:

$SE_{\Delta C,t0 \rightarrow t1}$	= Standard error of mean carbon stock for the first inventory period (t CO_2e)
$SE_{t=0}$	= Standard error of mean carbon stock estimate at time t = 0 (t CO_2e)
SE_{t1}	= Standard error of mean carbon stock estimate at time t_1 (t CO_2e)

Step 2: Quantify the Standard Error for the Second Inventory Period

For the interval between t_1 and t, using permanent plots (correlated errors):

$$SE_{\Delta C,t1 \rightarrow t} = \sqrt{SE_{t_1}^2 + SE_t^2 - (2 \times \rho \times SE_{t1} \times SE_t)} \tag{A12}$$

Where:

$SE_{\Delta C,t1 \rightarrow t}$	= Standard error of mean carbon stock for the subsequent inventory period (t CO_2e)
SE_{t1}	= Standard error of mean carbon stock estimate at time t_1 (t CO_2e)
SE_t	= Standard error of the mean carbon stock estimate at time t (t CO_2e)
ρ	= Correlation coefficient between measurements at t_1 and t

Step 3: Compute Total Standard Error Across the Full Period

Assuming independent estimates across the two inventory periods (i.e., the $t_0 \rightarrow t_1$ period and the $t_1 \rightarrow t$ period are operationally distinct):

$$SE_{\Delta Ct0 \rightarrow t} = \sqrt{SE^2_{\Delta C,t0 \rightarrow t1} + SE^2_{\Delta C,t1 \rightarrow t}} \tag{A13}$$

$$\Delta C_{t0\rightarrow t} = C_t - C_{t0} \tag{A14}$$

Step 4: Calculate the Total Carbon Stock Change Across the Full Period

Or, if desired, express additively:

$$\Delta C_{t0\rightarrow t} = \Delta C_{t0\rightarrow t1} + \Delta C_{t1\rightarrow t} \tag{A15}$$

Step 5: Quantify the Final Uncertainty Deduction

$$UNC_t = \text{MIN}\left(100\%, \text{MAX}\left(0, \left(T \times \frac{SE_{\Delta C_{t0\rightarrow t}}}{\Delta C_{t0\rightarrow t}}\right) - 0.10\right) \times 100\right) \tag{A16}$$

DOCUMENT HISTORY

Version	Date	Changes
v1.0	28 Sep 2023	Initial version released
v1.1	14 May 2025	• Clarification of eligibility for area-based projects with existing forest cover • Updated requirements for planting density, spacing, accounting and ID for census-based projects • Updated methodology definitions • Revised requirements for pre-existing woody biomass removal • Clarified for soil disturbance accounting requirements • Clarified exclusions of projects involving timber harvest or ecosystem degradation. • Inclusion of use of remote sensing for establishing pre-existing biomass estimates. • Updates to uncertainty, ex-ante, and carbon pool quantification procedures • Clarifications and corrections to performance benchmark design, sampling, and equation • General edits for clarity, consistency, and improved readability