



VCS Methodology

VM0047

AFFORESTATION, REFORESTATION, AND REVEGETATION

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1 SOURCES

This methodology is based on the following [CDM](#) 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*

2 SUMMARY DESCRIPTION OF THE METHODOLOGY

Additionality and Crediting Method¹

Additionality	Performance Method or Project Method
Crediting Baseline	Performance Method or Project Method

The methodology provides two quantification approaches: area-based and census-based. It applies to afforestation, reforestation, and revegetation (ARR) activities and provides two quantification approaches:

4) Area that establish, increase, or restore vegetative cover in non-forest areas (both approaches) and activities that enhance forest carbon stocks in existing forests (area-based approach: only).

¹ See Section 7 for additional information.

1) ~~uses~~The area-based approach:

- a) ~~Uses~~ traditional plot-based sampling methods that scale biomass estimates per unit area to the project level using project area as the multiplier (i.e., the area within the project boundary);~~).~~
- b) ~~uses~~Uses a dynamic performance benchmark to demonstrate additionality and determine the crediting baseline at every verification. The performance benchmark is calculated from ex-post observations of business-as-usual changes in vegetative cover in matched control areas.
- c) ~~Projects may include~~May be used where project activities are direct (e.g., manual planting, broadcast seeding) and/or indirect ~~activities-~~activities that permit or facilitate~~permitting or facilitating~~ natural regeneration, like herbivory exclosures).

2) ~~Census~~The census-based approach:

- a) ~~is~~is applicable where the project activity does not result in a change in land use and where a complete census of plantings is practical (e.g., urban forestry, agroforestry, forest shelterbelts, plantings directed to rural homesteads, revegetation not meeting the forest definition);~~).~~
- b) Applies only where ARR project activities ~~must bear~~direct plantings;~~).~~
- c) ~~scales~~Scales biomass by planting unit to the project level using a complete census of planting units (i.e., the project boundary is defined by the individual planting units);~~).~~
- d) ~~uses~~Uses a project method to demonstrate additionality and determine the crediting baseline.

VM0054 Module for estimating leakage from ARR activities must be applied in conjunction with ~~this methodology-~~the area-based approach. It provides a standardized approach to account for leakage related to the displacement of pre-project agricultural activities caused by the baseline agent (activity-shifting leakage) or other actors (market leakage). Leakage in the census-based approach is set at zero.

3 DEFINITIONS

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

Control plot

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

Donor pool area

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

Managed forests

Forest lands managed for wood products such as saw timber, pulpwood, and/or fuelwood

Matching covariates

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

Multivariate distance metric

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

Planting unit

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

Pre-existing woody biomass

Woody biomass, including aboveground, belowground, and dead wood in the project area prior to the project implementation

~~Control plot~~

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

Project plot

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

Site preparation

Activities undertaken as part of the ARR project activity 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 ~~that has~~with demonstrated correlation with terrestrial aboveground carbon stocks (e.g., normalized difference fraction index from Landsat imagery, ~~or~~ average canopy height derived from LiDAR)

Woody biomass

Biomass in plants with hard, lignified stems, ~~for example, (e.g.,~~ trees, shrubs, palms, and bamboo).

4 APPLICABILITY CONDITIONS

This methodology applies to ARR activities.

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

The methodology is applicable under the following conditions:

- 1) Project activities increase vegetative cover; and
- 2) Area-based, census-based, or a combination of the two quantification approaches may be used provided that approach-specific applicability conditions are met. Approaches must be selected at the project start date and used for the entire project crediting period. Where the two approaches are used together, they must be applied in non-overlapping areas defined at the project start (see Section 5 on the delineation of spatial boundaries to ensure non-overlap).
- 3) The project start date is no later than the commencement of any site preparation activities.
- 4) Where projects take place on organic soils or wetlands and manipulate the water table, they must be developed using a multiple project activity design applying this methodology to account for above-ground biomass and using a Wetland Restoration and Conservation methodology to account for other carbon pools (e.g., VM0036 Methodology for Rewetting Drained Temperate Peatlands).

This methodology is not applicable under the following conditions:

- ~~3)5) Project activities involve mechanical removal offsite or burning of significant² stocks of pre-existing dead wood (e.g., for site preparation). Where project site preparation includes chipping, mastication, or machine piling, all material must remain onsite within the project boundary.~~
- ~~4)6) Project activities take place in tidal wetlands (e.g., mangroves, salt marshes).~~
- ~~5) Project activities that occur on organic soils or in wetlands and result in a manipulation of the water table. Planting species that do not naturally occur in organic soils or wetlands is considered a manipulation of the water table. Where projects take place on organic soils or wetlands and manipulate the water table, they must be developed using a multiple project activity design applying this methodology and a Wetland Restoration and Conservation~~

² Significance determined by applying procedures in Appendix 2.

methodology (e.g., VM0036 Methodology for Rewetting Drained Temperate Peatlands). In such cases, the project activities must comply with all applicable conditions of the selected Wetland Restoration and Conservation methodology and this methodology.

- 7) This methodology cannot be applied where a project plants on wetland or organic soils and introduces plant species that are not native to wetlands or organic soils within the ecoregion of the project³.
- 8) Project activities enhance carbon stocks in existing managed forests. Managed forests are managed for wood products under either the baseline scenario or the project scenario.⁴

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

Area-based approach:

- 6) Project activities produce continuous tree and/or shrub cover on any contiguous area exceeding one hectare.
- 9) Projects may include are direct planting (e.g., manual planting, broadcast seeding) and indirect project or instance area exceeds one contiguous hectare.
- 7) Project activities are of any size, indirect establishment (e.g., activities that permit or facilitate natural regeneration, like herbivory exclosures).
- 10) Census, and detectable using remote sensing necessary for the area-based approach.

Census-based approach

- 8) 11) Project activity must be direct planting (i.e., must not involve facilitated natural regeneration).
- 9) Project activity must or instance area does not produce continuous tree and/or shrub cover on any exceed one contiguous area exceeding one hectare.
- 12) Individual planting units of woody biomass must (such as trees, shrubs, or bamboo clumps) must:
 - a) be clearly defined (e.g., tree, shrub, bamboo clump) and identifiable in the field, with each planting unit given a physical marker onsite with a

³ Note: Planting species that do not naturally occur in organic soils or wetlands is considered a manipulation of the water table.

⁴ Projects in areas with existing forest cover managed for wood products are considered under the VCS Program Improved Forest Management category; such activities are not eligible under this methodology.

- ~~b) have a unique ID and location recorded by,~~
- ~~10)c) be marked with a geolocated GPS waypoint, with a minimum 5m accuracy of five meters⁵(Note: Smart phone or handheld GPS may be used).~~
- ~~11) Project activity must:~~
- a) ~~occur within an area classified as non forest for the past ten years with less than 10% percent Clearing of pre-existing woody biomass cover; and/or within 10 years of the project start must not have been done to enable the generation of GHG credits.⁶~~
- ~~13) occur in~~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,⁷ or in “settlements”, or “other lands” land use category/categories.⁸~~
- ~~12)14) An initial complete census of all planting units at t = 0 must be conducted.~~
- ~~13) Projects are considered ineligible if woody biomass, which serves a similar purpose as the planting units in the project, has been removed within the last ten years (confirmed via pre-project photos and/or attestation)~~
- ~~14)15) Any soil disturbance from the project activity (i.e., from site preparation):~~
- a) ~~occursOccurs~~ only once during the project crediting period (i.e., at site preparation); or
- b) ~~doesDoes~~ not involve soil inversion to a depth exceeding 25 cm (e.g., that would result from a moldboard plow).

5 PROJECT BOUNDARY

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

⁵Based on growth traits of planted species, individual planting unit crowns are unlikely to expand beyond 10 meters radius from their originally established location.

⁶ Site preparation is considered part of the project activity.

⁷ i.e., That is, 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

⁸ Land use category as defined by the IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 AFOLU, Chapter 3 Consistent Representation of Lands.

defined at the project start.

Area-based ~~approach~~ Approach

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

Selected carbon pools included in the project boundary in the area-based baseline and project scenarios are listed in [Table 1](#).

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

<u>Carbon Pool</u>	<u>Included?</u>	<u>Justification/Explanation</u>
<u>Aboveground woody biomass</u>	<u>Yes</u>	<u>Major carbon pool</u>
<u>Aboveground non-woody biomass</u>	<u>Yes/Optional</u>	<u>Must be included where the project activity significantly reduces the carbon pool as per Appendix 2.</u> <u>Otherwise, this carbon pool is optional.</u>
<u>Belowground woody biomass</u>	<u>Yes</u>	<u>Major carbon pool</u>
<u>Belowground non-woody biomass</u>	<u>Yes/Optional</u>	<u>Must be included where the project activity significantly reduces the carbon pool as per Appendix 2.</u> <u>Otherwise, this carbon pool is optional.</u>
<u>Dead wood</u>	<u>Optional</u>	<u>Carbon stock in this pool may increase due to implementation of the project activity.</u>
<u>Litter</u>	<u>Yes/Optional</u>	<u>Must be included where the project activity significantly reduces the carbon pool (i.e., is not determined to be de minimis).</u> <u>Otherwise, this carbon pool is optional.</u>
<u>Soil organic carbon (SOC)</u>	<u>Yes/Optional</u>	<u>Must be included where soil disturbance from the project activity (i.e., from site preparation):</u> <u>1) Occurs more than once during the project crediting period; or</u> <u>2) Involves soil inversion to a depth exceeding 25 cm (e.g., that would result from a moldboard plow).</u>

		<u>Where the project activity does not cause soil disturbance, the inclusion of this carbon pool is optional.</u>
<u>Harvested wood products</u>	<u>Excluded</u>	<u>Conservative to exclude</u>

Census-based Approach

Census based approach

The relevant spatial boundary for the census-based approach is a 10-meter radius buffer around the recorded GPS location of each planting unit. This is required to ensure accounting boundaries do not overlap when area-based and census-based approaches are used in the same project.

Planting units in the same census-based project instance may be closer together than ten meters. This spatial boundary ~~will~~ also ~~be~~ used to assess VCS eligibility and methodology applicability conditions. In the census-based approach, a project area is not used for scaling estimated carbon stocks. ~~Scaling~~ Instead, scaling is based on the number of planting units, N_i .

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

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

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

<u>Carbon Pool</u>	<u>Included?</u>	<u>Justification/Explanation</u>
<u>Aboveground woody biomass</u>	<u>Yes</u>	<u>Major carbon pool</u>
<u>Aboveground non-woody biomass</u>	<u>Yes/Optional</u>	<u>Must be included if the project activity significantly reduces the carbon pool as per Appendix B. For other cases this carbon pool is optional.</u>
<u>Belowground woody biomass</u>	<u>Yes</u>	<u>Major carbon pool</u>
<u>Belowground non-woody biomass</u>	<u>Yes/Optional</u>	<u>Must be included if the project activity significantly reduces the carbon pool as per Appendix B. For other cases this carbon pool is optional.</u>

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

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

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

Carbon pools and GHG emissions sources may be deemed de minimis where it is reasonably demonstrated that the combined decrease in carbon stocks or increase in GHG emissions amounts to less than 5% of the total GHG benefit generated by the project. Appendix 2 of this methodology must be applied to demonstrate that the decrease in carbon stocks or increase in GHG emissions together amount to less than 5% of the total GHG benefit generated by the project.

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

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

Source	Gas	Included?	Justification/Explanation	
Baseline	Burning of biomass (whether by natural or anthropogenic causes)	CO ₂	No	Conservative to exclude
		CH ₄	No	Conservative to exclude
		N ₂ O	No	Conservative to exclude
	Emissions from nitrogen fertilizer	CO ₂	No	Conservative to exclude
		CH ₄	No	Conservative to exclude
		N ₂ O	No	Conservative to exclude
	Burning of fossil fuels	CO ₂	No	Conservative to exclude
		CH ₄	No	Conservative to exclude
		N ₂ O	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 ₂ O	Yes	May be a significant source
	Emissions from nitrogen fertilizer	CO ₂	No	Conservative to exclude
		CH ₄	No	Conservative to exclude
		N ₂ O	Yes	May be a significant source
	Burning of fossil fuels	CO ₂	No	De minimis
		CH ₄	No	De minimis
		N ₂ O	No	De minimis

6 BASELINE SCENARIO

Area-based ~~approach~~ Approach

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

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

Census-based ~~approach~~ Approach

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

- 1) ~~occur~~ Occur within an area with pre-existing woody biomass cover of less than ~~ten~~ percent; 10%; and/or
- 2) ~~occur~~ Occur in an area subject to continuous cropping, in settlement(s), or on lands categorized as “other ~~lands~~ lands.”

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

7 ADDITIONALITY

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

Area-based ~~approach~~ Approach

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

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

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

Census-based ~~approach~~ Approach

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

Step 1: Regulatory surplus

Step 3: Investment barrier

Step 4: Common practice

Step 1: Regulatory Surplus

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

Step 2: Performance Benchmark

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

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

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

Step 3: Investment Barrier

Methodologies applying an investment barrier analysis to assess additionality must ~~select~~ use a benchmark analysis or investment comparison analysis. Project proponents must apply the procedures and requirements in the latest version of the *VCS Methodology Requirements*.⁹

Step 4: Common Practice

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

⁹ At the time of approval of this methodology, *VCS Methodology Requirements, v4.4* is the most recent version. The relevant procedures and requirements for the investment analysis are ~~in~~ included in ~~section~~ Section 3.5.5 of this version.

~~Projects~~ Project proponents must use the most recent version of the *VCS Methodology Requirements*.

- 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. If national or sub-national programs provide incentives for afforestation, reforestation, or revegetation activities at the subnational level, the geographic domain must be further constrained to reflect similar incentives and market conditions as those presented in the project area (e.g., proximity to nurseries or wood processing infrastructure).
- 3) Identify a similar class of adopters or landowners (e.g., smallholder farmers).
- 4) Survey a representative sample of similar landowners from within the relevant geographic domain within five years of the project start date.
- 5) Calculate the (cumulative) adoption rate (%)(percentage) of the project activity ofby 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 equals is equal to or exceeds higher than 15%, the project activity is common practice and is not additional.

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

8 QUANTIFICATION OF ESTIMATED CARBON DIOXIDE REMOVALS

8.1 Baseline Emissions

Area-based ~~approach~~ Approach

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

Census-based ~~approach~~ Approach

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

8.2 Project Emissions

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

Figure 1: Summary of Calculations for Area-based Approach

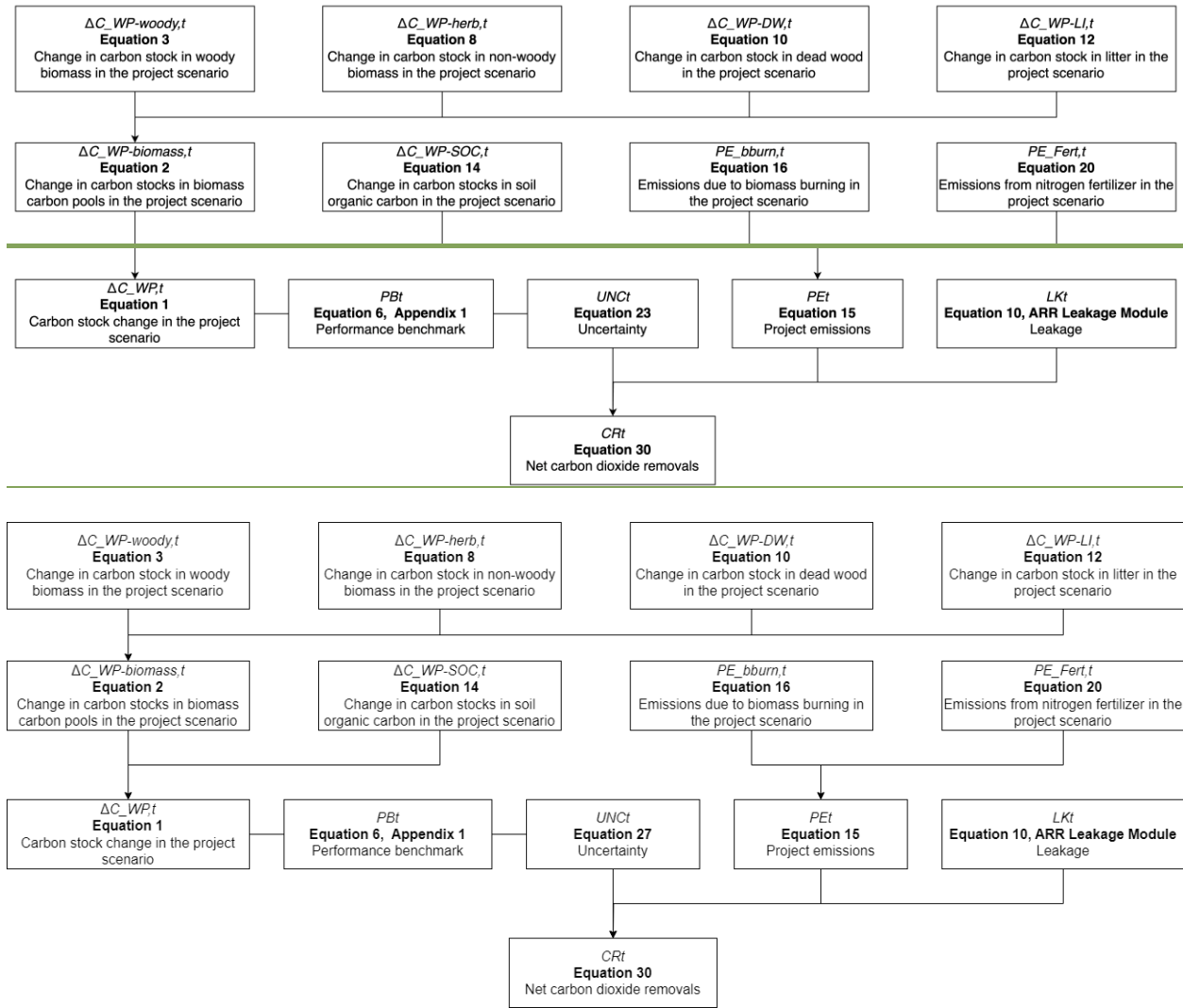
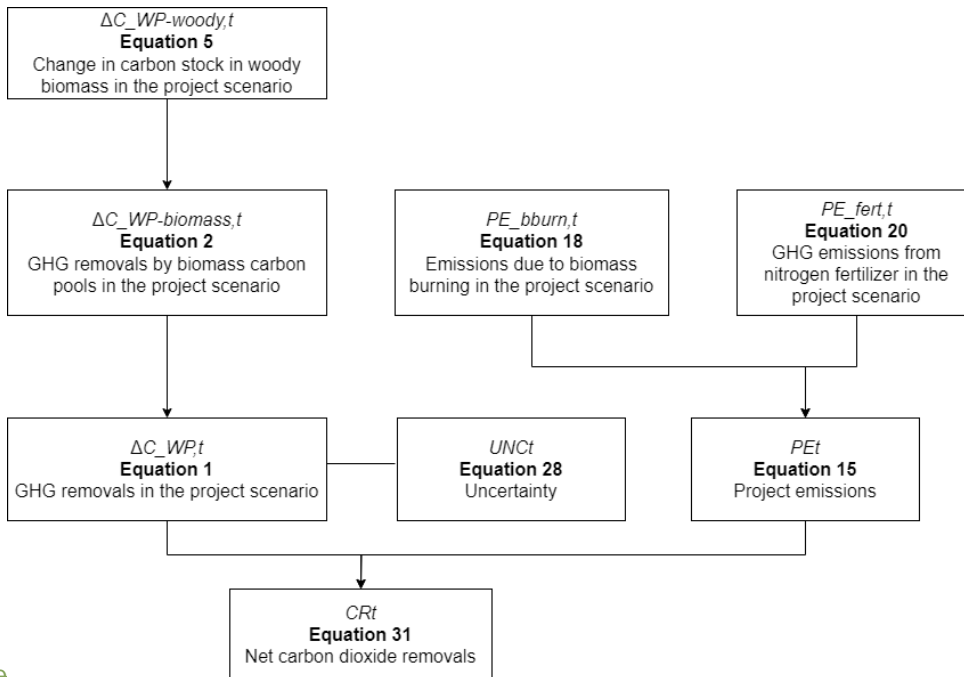
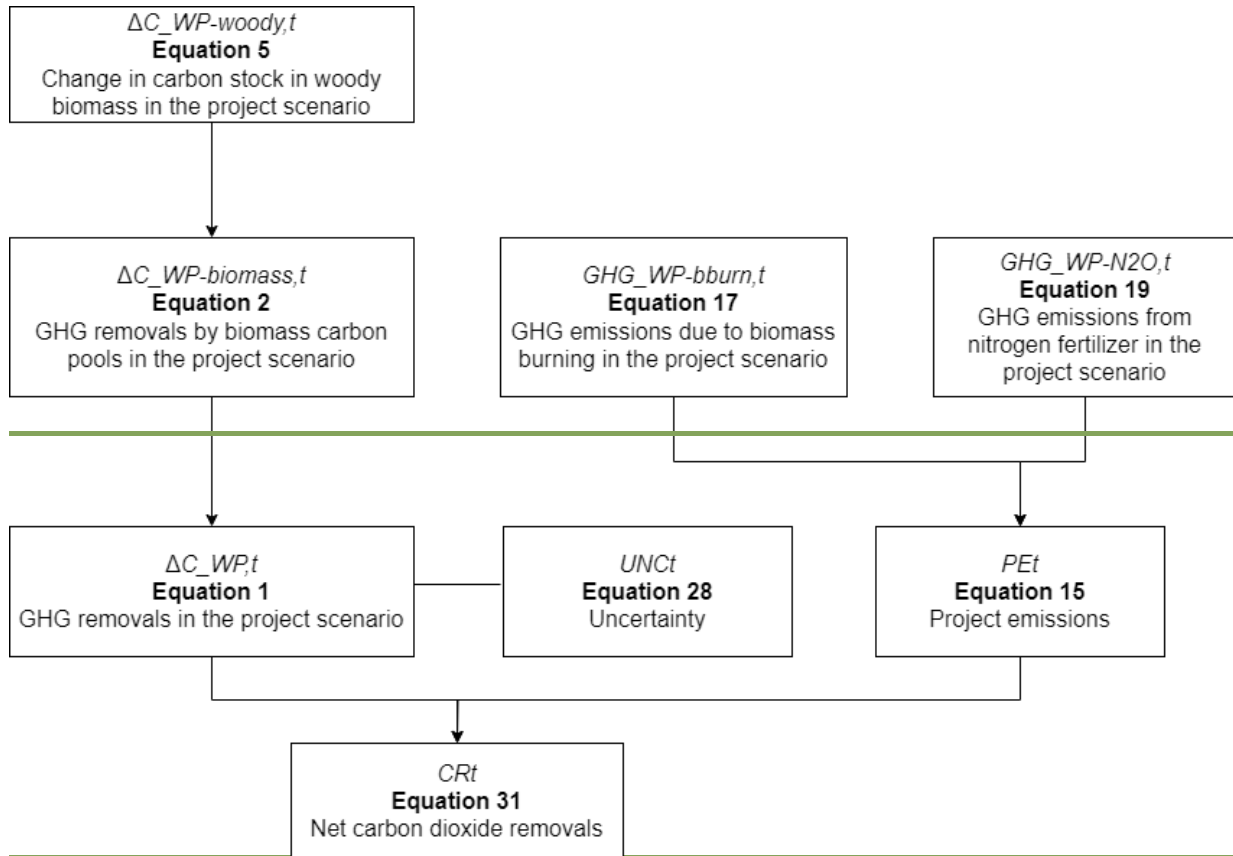
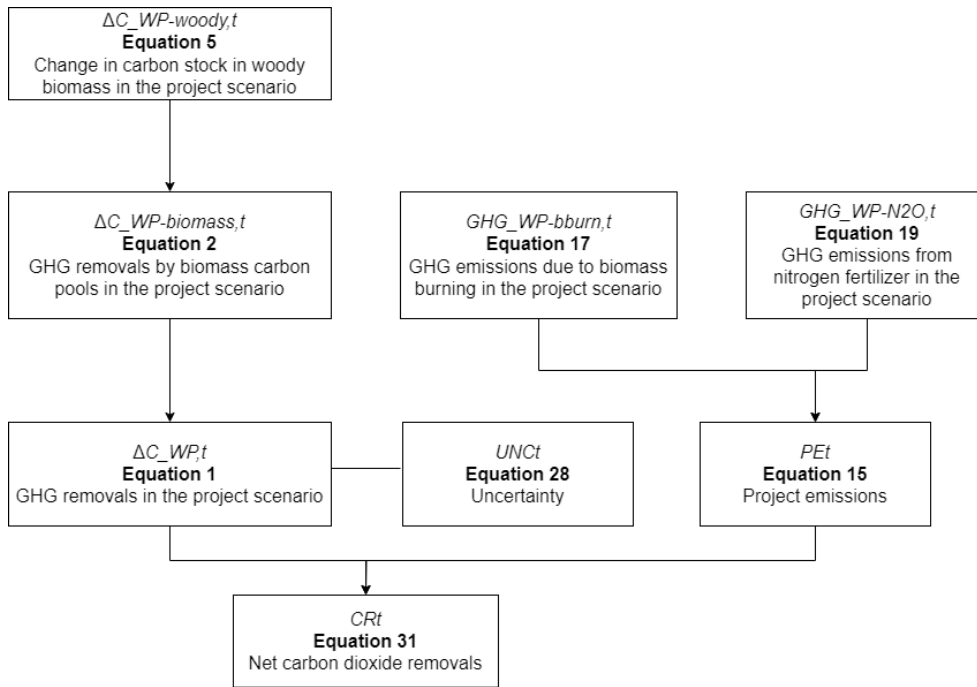


Figure 2: Summary of Calculations for Census-based Approach-


Leakage



In the census-based approach, leakage and performance benchmark are not included in calculations (implicitly set equal to zero), soil organic carbon is excluded, and biomass carbon is restricted to (live) woody biomass.

8.2.1 Project Carbon Stock Changes

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

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

Where:

$\Delta C_{WP,t}$	=	Project carbon stock change <u>through</u> year t (t CO ₂ e)
$\Delta C_{WP-biomass,t}$	=	Change in carbon stock in biomass carbon pools in the project scenario through year t (t C)
$\Delta C_{WP-SOC,t}$	=	Change in <u>carbonSOC</u> stock in <u>SOC in</u> 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

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

Where:

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

For the census-based quantification approach, excluded pools (SOC, non-woody biomass, dead wood, and litter) are assigned a value of zero in Equations (1) and (2).

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

- ~~1) Soil disturbance from site preparation did not involve soil inversion to a depth exceeding 25 cm (e.g., that would result from a moldboard plow), and~~
- ~~2) Site preparation does not involve significant reductions of woody biomass (see Section 8.2.1.1 for details on pre-existing woody biomass).~~

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

8.2.1.1 Woody Biomass

Area-based ~~quantification~~Quantification

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

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

Where:

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

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

Where:

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

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

Pre-existing woody biomass

Pre-existing woody biomass must be measured and extrapolated using Equation (4) at $t = 0$, immediately prior to initiation of the project activity (i.e., before site preparation). ~~Where initial stocks are measured at $t > 0$, pre-existing woody biomass is equal to the initial stock measurement. Any;~~ any clearing of pre-existing woody biomass as part of the project activity (e.g., due to site preparation) must be ~~estimated using the stock difference method. Where the slope of a linear regression of stocking index values (see Appendix 1) from time $t = -10$ to $t = 0$, including site preparation, is significant and negative, clearing of pre-existing biomass is indicated. In this case, the project proponent must demonstrate that the clearing did not take place to create GHG credits as follows:~~ accounted for. Where direct field measurements of woody biomass are not available for $t = 0$, $C_{WP-woody-AB,t=0}$ may be estimated as the upper 90% confidence bound of a stocking index-based (see Appendix 1) model prediction (regression error) of aboveground woody biomass. The model relating aboveground woody biomass to the selected stocking index must meet the requirements listed in the parameter table for stocking index in Appendix 1 (i.e., be significantly correlated with aboveground biomass, substantiated with published or peer-reviewed studies and statistically validated with direct measurements from the project ecoregion, as defined at the biome level).

- ~~1) The prior clearing was the result of natural disturbances such as fires, hurricanes, or floods (e.g., using aerial imagery); or~~
- ~~2) The prior clearing was conducted by actors with no relationship to the project proponent or landowner (e.g., via community surveys or law enforcement records); or~~
- ~~3) The consideration of carbon finance post dated and did not incentivize the clearing event (e.g., via a feasibility study, communications with a carbon project developer, or community surveys indicating little local knowledge or engagement on carbon projects at the time of the clearing).~~

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

Census-based ~~quantification~~ Quantification

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

$$\Delta C_{WP-woody,t} = C_{WP-woody,t} \quad (5)$$

Where:

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

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

$$C_{WP-woody,t} = N \times (1 - M_t) \times \del{C_{WP-woody-pu_avg,t}} C_{WP-woody-pu_avg,t} \quad (6)$$

Where:

- $C_{WP-woody,t}$ = Average carbon stock in woody biomass in the project scenario in year t (t C)
- N = Initial population size (number of planting units)
- M_t = Mortality through year t ~~(percent)(%)~~
- $C_{WP-woody-pu_avg,t}$ = Average carbon stock in woody biomass per planting unit ~~(pu)~~ in the project scenario in year t (t C/pu)
- t = 1, 2, 3, ..., t years elapsed since the project start date

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

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

Where:

- $C_{WP-woody-pu_avg,t}$ = Average carbon stock in woody biomass per planting unit ~~(pu)~~ in the project scenario in year t (t C/pu)
- n_t = Number of planting units sampled in year t (integer)
- $B_{WP-woody-AB,pu,t}$ = Estimated biomass stock in aboveground woody biomass in sampled planting unit pu in the project scenario in year t (t d.m.)

R	=	Root to shoot ratio (t root d.m./t shoot d.m.)
CF	=	Carbon fraction of dry biomass (t C/t d.m.)
t	=	1, 2, 3, ..., t years elapsed since the project start date

8.2.1.2 Non-Woody Biomass

Area-based ~~quantification~~ Quantification

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

$$C_{WP-herb,t} = DM_{WP-herb,t} \times CF \quad (9)$$

Where:

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

Census-based ~~quantification~~ Quantification

Not ~~Applicable.~~
applicable.

8.2.1.3 Dead Wood

Area-based ~~quantification~~ Quantification

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

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

Where:

$\Delta C_{WP-DW,t}$	=	Change in carbon stock in dead wood in the project scenario through year t (t C)
A	=	Area (ha)
$C_{WP-DW,t}$	=	Average carbon stock in dead wood in year t (t C/ha)

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

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

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

Where:

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

Census-based ~~quantification~~ Quantification

Not applicable.

8.2.1.4 Litter

Area-based ~~quantification~~ Quantification

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

Where:

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

$$C_{WP-LI,t} = DM_{WP-LI,t} \times CF \quad (13)$$

Where:

$C_{WP-LI,t}$ = Average carbon stock in litter in the project scenario in year t (t C/ha)
 $DM_{WP-LI,t}$ = Average litter dry mass per hectare in the project scenario in year t (t d.m./ha)
 CF = Carbon fraction of dry biomass (t C/t d.m.)

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

Census-based ~~quantification~~ Quantification

Not applicable.

8.2.1.5 Soil Organic Carbon

Area-based ~~quantification~~ Quantification

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

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

Where:

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

Census-based ~~quantification~~ Quantification

Not applicable.

8.2.2 Project Emissions from Biomass Burning and Fertilizer Use

~~8.2.2 Project emissions result from biomass burning and use of fertilizer.~~

$$PE_t = PE_{bburn,t} + PE_{fert,t} \quad (15)$$

~~The project emissions result from biomass burning and use of fertilizer.~~

Where:

- PE_t = Project emissions from biomass burning and fertilizer in year t (t CO₂e)
- $PE_{bburn,t}$ = Project emissions due to biomass burning in year t (t CO₂e)
- $PE_{fert,t}$ = Project emissions from nitrogen fertilizer in year t (t CO₂e)

8.2.2.1 Emissions from Biomass Burning

Area-based quantification

Quantification

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

Where:

$PE_{bburn,t}$	= Project emissions due to biomass burning in year t (t CO ₂ e)
$A_{burn,t}$	= Area burned in the monitoring interval ending in year t (ha)
GWP_g	= Global warming potential for gas g (dimensionless)
EF_g	= Emission factor for gas g (kg gas/t d.m. burned)
$B_{WP,t}$	= Average aboveground biomass stock subject to burning in the project scenario in the monitoring interval ending in year t (t d.m./ha)
$COMF$	= Combustion factor (dimensionless)
t	= 1, 2, 3, ..., t years elapsed since the project start date
g	= 1, ..., G greenhouse gases (methane and nitrous oxide) (dimensionless)
10^{-3}	= Conversion of kg CO ₂ e to tCO ₂ e

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

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

Where:

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

Census-based ~~quantification~~Quantification

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

Where:

GWP_g	=	Global warming potential for gas g (dimensionless)
EF_g	=	Emission factor for gas g (kg/t d.m. burned)
$B_{WP,t}$	=	Aboveground biomass stock subject to burning in the project scenario in the monitoring interval ending in year t (t d.m.)
$COMF$	=	Combustion factor (dimensionless)
t	=	1, 2, 3, ..., t years elapsed since the project start date
g	=	1, ..., G greenhouse gases <u>not including CO₂</u> (methane and nitrous oxide) (dimensionless)

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

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

Where:

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

8.2.2.2 Emissions from Fertilizer Application

Area- and ~~census~~Census-based ~~quantification~~Quantification

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

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

Where:

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

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

Where:

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

$$F_{wp,SN,t} = M_{wp,SF,t} \times NC_{wp,SF,t} \quad (22)$$

Where:

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

$$F_{wp,ON,t} = M_{wp,OF,t} \times NC_{wp,OF,t} \quad (23)$$

Where:

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

$$PE_{N,indirect,t} = Nfert_{wp,volat,t} + Nfert_{wp,leach,t} \quad (24)$$

Where:

- $PE_{N,indirect,t}$ = Indirect nitrous oxide emissions due to fertilizer use in the project scenario in monitoring interval ending in year t (t CO₂e)
 $Nfert_{wp,volat,t}$ = Indirect nitrous oxide emissions produced from atmospheric deposition of N volatilized due to nitrogen fertilizer use in year t (t CO₂e)
 $Nfert_{wp,leach,t}$ = Indirect nitrous oxide emissions produced from leaching and runoff of N, in regions where leaching and runoff occurs, due to nitrogen fertilizer use in year t (t CO₂e)

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

Where:

- $Nfert_{wp,volat,t}$ = Indirect nitrous oxide emissions produced from atmospheric deposition of N volatilized due to nitrogen fertilizer use in year t (t CO₂e)
 $F_{wp,SN,t}$ = Synthetic N fertilizer applied in the project scenario in year t (t N)
 $Frac_{GASF}$ = Fraction of all synthetic N added to soils that volatilizes as NH₃ and NO_x (dimensionless)
 $F_{wp,ON,t}$ = Organic N fertilizer applied in the project scenario in year t (t N)
 $Frac_{GASM}$ = Fraction of all organic N added to soils that volatilizes as NH₃ and NO_x (dimensionless)
 EF_{Nvolat} = Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces (t N₂O-N/(t NH₃-N + NO_x-N volatilized))
 GWP_g = Global warming potential for gas g (here, nitrous oxide) (dimensionless)

- 44/28 = Ratio of molecular weight of N₂O to molecular weight of N (applied to convert N₂O-N emissions to N₂O emissions) (unitless)
- t* = 1, 2, 3, ..., *t* years elapsed since the project start date

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

Where:

- $Nfert_{wp,leach,t}$ = Indirect nitrous oxide emissions produced from leaching and runoff of N, in regions where leaching and runoff occurs, due to nitrogen fertilizer use in year *t* (t CO₂e)
- $F_{wp,SN,t}$ = Synthetic N fertilizer applied in the project scenario in year *t* (t N)
- $F_{wp,ON,t}$ = Organic N fertilizer applied in the project scenario in year *t* (t N)
- $Frac_{LEACH}$ = Fraction of synthetic or organic N added to soils that is lost through leaching and runoff, in regions where leaching and runoff occurs (dimensionless)
- EF_{Nleach} = Emission factor for nitrous oxide emissions from leaching and runoff (t N₂O-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 N₂O to molecular weight of N (applied to convert N₂O-N emissions to N₂O emissions) (unitless)
- t* = 1, 2, 3, ..., *t* years elapsed since the project start date

8.3 Leakage Emissions

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

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

8.4 Uncertainty

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

Area-based ~~quantification~~Quantification

Uncertainty in area estimation is assumed to be zero and is addressed via complete (and accurate) GIS boundaries of the project area, and by applying QA/QC procedures specified in the parameter table for A. (Section 9.1). The performance benchmark is assumed to have zero uncertainty.

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

$$\begin{aligned}
 UNC_t = MIN & \left(100\%, MAX \left(0, \left(\sum_{p=1}^n (U_{p,t=0} \times C_{p,t=0})^2 + \sum_{p=1}^n (U_{p,t} \times C_{p,t})^2 \right)^{\frac{1}{2}} \right. \right. \\
 & \left. \left. \times \left(\frac{1}{\Delta C_{WP-biomass,t} + \Delta C_{WP-SOC,t}} \right) - 10\% \right) \right) \quad (27)
 \end{aligned}$$

Where:

UNC_t	= Uncertainty in cumulative removals through year t (percent)(%)
$U_{p,t}$	= Percentage uncertainty (expressed as 90- percent % confidence interval as a percentage of the mean) in carbon stock estimate of pool p (representing woody biomass, non-woody biomass, dead wood, litter, and SOC) in the project scenario in year t (percent)(%)
$C_{p,t}$	= Carbon stock estimate of pool p (representing woody biomass, non-woody biomass, dead wood, litter, and SOC) in the project scenario in year t (t CO ₂ e)
$\Delta C_{WP-biomass,t}$	= Change in carbon stock in biomass carbon pools in the project scenario through year t (t CO₂e)
$\Delta C_{WP-SOC,t}$	= Change in carbon stock in SOC in the project scenario through year t (t CO₂e)
t	= 1, 2, 3, ..., t years elapsed since the project start date

Census-based ~~quantification~~Quantification

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

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

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

Where:

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

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

Where:

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

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

8.5 Estimated Carbon Dioxide Removals

Area-based ~~quantification~~Quantification

$$CR_t = \left(\left(\Delta C_{WP,t} \times (1 - PB_t) \times (1 - UNC_t) \right) - LK_t \right) - PE_t \quad (30)$$

$$- \left(\left(\Delta C_{WP,t-1} \times (1 - PB_{t-1}) \times (1 - UNC_{t-1}) \right) - PE_{t-1} - LK_{t-1} \right)$$

Where:

CR_t	=	Carbon dioxide removals from the project activity in <u>from year t to $t-1$</u> (t CO ₂ e)
$\Delta C_{WP,t}$	=	Project carbon stock change <u>in through</u> year t (t CO ₂ e)

PB_t	= Performance benchmark for the monitoring interval ending in year t (percent)(%)
LK_t	= Leakage through year t (t CO ₂ e)
PE_t	= Project emissions from biomass burning and fertilizer in year t (t CO ₂ e)
UNC_t	= Uncertainty in cumulative removals through year t (percent)(%)
t	= 1, 2, 3, ..., t years elapsed since the project start date

Census-based ~~quantification~~ Quantification

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

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

Where:

CR_t	= Carbon Annual carbon dioxide removals from the project activity in from year $t-x$ to t (t CO ₂ e/yr)
$\Delta C_{WP,t}$	= Project carbon stock change in through year t (t CO ₂ e)
PE_t	= Project emissions from biomass burning and fertilizer in year t (t CO ₂ e)
t	= 1, 2, 3, ..., t years elapsed since the project start date

~~Where~~ = Length of the monitoring period in years

~~monitoring intervals are longer than one year, periodic removals are first calculated for the monitoring interval using the equations above (substituting $t-1$ for t minus length of monitoring interval in years) and then~~

~~annualized by
 dividing
 periodic
 removals by
 the length of
 the monitoring
 interval in
 years. This
 produces equal
 CR_t assigned to
 each year in
 the monitoring
 interval. x~~

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

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

8.6 Ex-Ante Estimation

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

- ~~1)~~ At the time t of validation, [ex ante](#) estimates must be made for the ~~10-year~~ [length of the crediting period from time \$t\$ to \$t+10\$](#)
- ~~2)~~ At the time t of every verification, estimates may be updated for the 10-year period from time t to $t+10$ (i.e., every verification may be accompanied by an ex-ante estimate projecting 10 years into the future)
- ~~3)~~ 1) Projected changes in biomass must be based on growth and yield models constructed with data and parameters that conservatively represent the project activity.
- ~~4)~~ 2) Any harvest regimes or forest management activities ~~planned for the 10-year period over which the ex-ante calculations are projected~~ must be incorporated in ~~modelling~~ [when modeling](#) the project scenario.
- ~~3)~~ A minimum uncertainty deduction of 10-~~percent~~% must be applied. An uncertainty deduction greater than 10-~~percent~~% may be selected by the project proponent if they wish to be more conservative.

5)4) _____ The ex-ante estimate of removals is derived by executing Equations (1) and (2) with parameters estimated as follows: $\Delta C_{WP-biomass,t}$: Modelled growth and yield values. The output of the growth and yield model must provide an estimate in value of tC, which provides the value for $\Delta C_{WP-biomass,t}$ used in Equation (2).

a) $\Delta C_{WP-biomass,t}$ 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 $\Delta C_{WP-biomass,t}$ used in Equation (2).

5) The performance benchmark is determined by applying the procedure in Appendix 1 with parameters estimated as follows:

6) ΔSI_{wp} : Modelled modeled from relationship with growth and yield values (i.e., regression). The: the growth and yield projection will also be used to derive an estimate of stocking index value ΔSI_{wp} . This is done by using a regression model from a published study or validation dataset¹⁰ that establishes the relationship between tC in biomass and stocking index, ΔSI_{wp} .

7)a) $\Delta SI_{control}$: Modelled modeled based on performance between t and t - 10 assuming a linear relationship (e.g., if $\Delta SI_{control}$ increased by 10% over is equal to the past ten years, the same increase would be slope from t-10 to t0 assumed over the next ten years)-entire crediting period).

8)6) _____ All other carbon pools (i.e., soil organic carbon) and GHG emission sources can may be assumed to be zero unless it is not conservative to do so.

9 MONITORING

9.1 Data and Parameters Available at Validation

Data/Parameter	A
Data unit	ha
Description	Project area

¹⁰ "Validation dataset" is used here in its form as generally accepted terminology within modeling. In this specific instance it does not relate to validation under the VCS Program.

Equations	(3), (8), (10), (12), (14)
Source of data	Calculated from GIS data
Value applied	Project-specific
Justification of choice of data or description of measurement methods and procedures applied	Delineation of the project area may use a combination of GIS coverages, ground survey data with GPS, remote imagery (satellite or aerial photographs) or other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, clear landmarks or other intersection points.
Purpose of data	Calculation of project emissions using the area-based quantification approach
Comments	The project activity may contain more than one discrete area of land. Each discrete area of land must have a unique geographic identification.

Data/Parameter	R
Data unit	dimensionless
Description	Root to shoot ratio (i.e., ratio of belowground (root) biomass to aboveground biomass, per unit area or per stem)
Equations	(4) (4), (7)
Source of data	<p>The source of data must be chosen as follows:</p> <p>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:</p> <ol style="list-style-type: none"> Values specific to the forest type within the same ecoregion (defined at the biome level following Olson et al., 2001¹¹) or Holdridge life-zone¹² as the region in which the project is located; or

¹¹ Available at: <https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world?https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world>

¹² Available at: <http://iridl.ldeo.columbia.edu/SOURCES/.ECOSYSTEMS/.Holdridge/present+.life-zone/downloadsGeoTiff.html>

	<p>b) Global values specific to the forest type (e.g., from Table 4.4 in Chapter 4 of the <i>2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories</i>).</p> <p>Otherwise (e.g., in the case of monoculture plantations), <i>R</i> must be chosen from the following as available, listed in descending order of preference:</p> <p>c) Values specific to the species, genus or family within the same ecoregion or Holdridge life-zone as the region in which the project is located; or</p> <p>d) Global values specific to the species, genus or family (e.g., from Table 4.4 in Chapter 4 of the <i>2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories</i>).</p> <p>Note that where <u>Where</u> a global <i>R</i> 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.</p>
Value applied	Project-specific
Justification of choice of data or description of measurement methods and procedures applied	See “Source of data”
Purpose of data	Calculation of project emissions using the area-based and census-based quantification approaches
Comments	None

Data/Parameter	<i>CF</i>
Data unit	t C/t d.m.
Description	Carbon fraction of dry biomass
Equations	(7), (9), (11), (13), (17)
Source of data	<i>IPCC 2006 Guidelines for National Greenhouse Gas Inventories</i>
Value applied	0.47
Justification of choice of data or description of	IPCC is a reputable source approved under the VCS <u>Standard</u> .

measurement methods and procedures applied	
Purpose of data	Calculation of project emissions using the area-based and census-based quantification approaches
Comments	None

Data/Parameter	N
Data unit	Integer
Description	Initial population size (number of planting units)
Equations	(6), (19)
Source of data	Complete census/enumeration
Value applied	<p>The original population size, N, is established via administering and recording an initial complete census of all planting units. For each planting unit, the following must be recorded:</p> <ul style="list-style-type: none"> • <u>1</u>) Unique ID • <u>2</u>) Geo-referenced point of the location • <u>3</u>) Year planted • <u>4</u>) Species
Justification of choice of data or description of measurement methods and procedures applied	See “Source of data”
Purpose of data	Calculation of project emissions using the census-based quantification approach
Comments	Planting units must be clearly defined (e.g., tree, shrub, bamboo clump) and identifiable in the field.

Data/Parameter	$EF_{Ndirect}$
Data unit	t N ₂ O-N/t N applied

Description	Emission factor for direct nitrous oxide emissions from N additions due to synthetic fertilizers, organic amendments, and crop residues
Equations	(21)
Source of data	Table 11.1, Chapter 11 in Volume 4 of the <i>2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories</i>
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 using the census-based and/or area-based quantification approaches
Comments	Emission factor applicable to N additions from mineral fertilizers, organic amendments, and crop residues

Data/Parameter	$Frac_{GASF}$
Data unit	Dimensionless
Description	Fraction of all synthetic N added to soils that volatilizes as NH_3 and NO_x
Equations	(25)
Source of data	Table 11.3, Chapter 11 in Volume 4 of the <i>2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories</i>
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 using the census-based and/or area-based quantification approaches
Comments	None

Data/Parameter	Fra_{GASM}
Data unit	Dimensionless
Description	Fraction of all organic N added to soils that volatilizes as NH_3 and NO_x
Equations	(25)
Source of data	Table 11.3, Chapter 11 in Volume 4 of the <i>2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories</i>
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 using the census-based and/or area-based quantification approaches
Comments	None

Data/Parameter	EF_{Nvolat}
Data unit	t N_2O-N /(t NH_3-N + NO_x-N volatilized)
Description	Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces
Equations	(25)
Source of data	Table 11.3, Chapter 11 in Volume 4 of the <i>2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories</i>
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 using the census-based and/or area-based quantification approaches

Comments	None
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Data/Parameter	$Frac_{LEACH}$
Data unit	Dimensionless
Description	Fraction of synthetic or organic N added to soils that is lost through leaching and runoff
Equations	(26)(21)
Source of data	Table 11.3, Chapter 11 in Volume 4 of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Value applied	0.24
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS Standard .
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Comments	None

Data/Parameter	EF_{Nleach}
Data unit	t N ₂ O-N/t N leached and runoff
Description	Emission factor for nitrous oxide emissions from leaching and runoff
Equations	(26)
Source of data	Table 11.3, Chapter 11 in Volume 4 of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Value applied	0.011
Justification of choice of data or description of measurement methods and procedures applied	IPCC is a reputable source approved under the VCS Standard .

Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Comments	None

Data/Parameter	<i>COMF</i>
Data unit	Dimensionless
Description	Combustion factor
Equations	(16), (18)
Source of data	Default mean values in Table 2.6 of <i>IPCC 2019 Refinement to the 2006 Guidelines for National Greenhouse Gas Inventories</i>
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 using the census-based and/or area-based quantification approaches
Comments	None

Data/Parameter	EF_g
Data unit	kg/t d.m. burned
Description	Emission factor for gas <i>g</i>
Equations	(16), (18)
Source of data	Table 2.5, Chapter 2, Volume 4 of the <i>IPCC 2006 Guidelines for National Greenhouse Gas Inventories</i> (see and in the same document , Appendix 2: Emission factors for various types of burning for CH ₄ and N ₂ O)
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 using the census-based and/or area-based quantification approaches
Comments	None

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

9.2 Data and Parameters Monitored

Data/Parameter	M_t
Data unit	Percent%
Description	Mortality through year t
Equations	(6), (29)
Source of data	Complete re-enumeration, or sampling

Description of measurement methods and procedures to be applied	<p>If sampling, planting units must be representatively sampled from the census list on which parameter N is based, compiled prior to sampling. Stratification (e.g., sub-dividing the census list into annual cohorts) may be employed to improve precision but is not required. An appropriate representative sample would be a stratified systematic sample, within each annual cohort, selecting planting units systematically with a random start from the list of unique censused planting units.</p> <p>Planting units are assessed as dead where:</p> <ol style="list-style-type: none"> 1) Green vascular tissue (e.g., cambium of trees and shrubs) and green leaves are absent, or 2) It is not possible to relocate the planting unit.
Frequency of monitoring/recording	<p>Every 5 years or more frequently. Sampling for incidence of mortality may be conducted simultaneously with sampling planting units for biomass measurement.</p>
QA/QC procedures to be applied	<p>See “Description of measurement methods and procedures to be applied”</p>
Purpose of data	<p>Calculation of project emissions using the census-based quantification approach</p>
Calculation method	<p>Calculated as a percentage of a sample or census</p>
Comments	<p>None</p>

Data/Parameter	$C_{WP-woody-AB,t}$
Data unit	<p>t C/ha</p>
Description	<p>Average aboveground woody biomass stocks in the project scenario in year t (area-based quantification)</p>
Equations	<p>(4)</p>
Source of data	<p>Field measurement</p>
Description of measurement methods and procedures to be applied	<p>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.</p>

Plot-based sampling approaches (using area-based quantification) may be augmented using double or two-phase sampling approaches (e.g., 3P or ratio sampling). These approaches must include:

- 1) A complete census of an auxiliary variable (e.g., stocking index, see Appendix 1), and
- 2) A sample of direct field-based measurements used to determine the relationship (i.e., a ratio or regression) between aboveground woody biomass and the auxiliary variable.

All sample measurements must:

- a) Be demonstrated to be unbiased and derived from representative sampling;
- b) Ensure accuracy through adherence to best practices and quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection); and
- c) Apply fixed size thresholds onto 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 level⁴³ following [Olson et al., 2001](https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world)) or Holdridge (1967) life-zone⁴⁴ as the region in which the project is located, or
- ii) Global equations specific to the forest type.

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

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

⁴³ <https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world> <https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world>

⁴⁴ <http://iridl.ldeo.columbia.edu/SOURCES/.ECOSYSTEMS/.Holdridge/present+.life-zone/downloadsGeoTiff.html>

	<p>iv) Global equations specific to the species, genus or family.</p> <p>Note that whereWhere 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.</p> <p>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:</p> <p>Kershaw Jr, J. A., Ducey, M. J., Beers, T. W., & Husch, B. (2016). <i>Forest mensuration</i>. John Wiley & Sons.</p> <p>Avery, T. E., & Burkhardt, H. E. (2015). <i>Forest measurements</i>. Waveland Press.</p> <p>Measurement protocols must be detailed in standard operating procedures. Parameter tables for all attributes (e.g., diameter at breast height, total height) incorporated as independent variables in allometric equations must be included in the project description under “Data and Parameters Monitored.”</p>
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	To be determined by the project proponent and outlined in standard operating procedures governing field data collection
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	Tool VT0005 does not apply.

Data/Parameter	$B_{WP-woody-AB,pu,t}$
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 (census-based quantification)
Equations	(7), (19)
Source of data	Field measurement

Description of measurement methods and procedures to be applied

Aboveground woody biomass is measured via representative sampling from N planting units.

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

All sample measurements must:

- 1) Be demonstrated to be unbiased and derived from representative sampling;
- 2) Ensure accuracy through adherence to best practices and quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection); and
- 3) Apply fixed size thresholds onto independent variables used in biomass estimation (e.g., diameter at breast height, diameter at root collar, height), to be maintained through the crediting period.

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

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

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

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

Attributes (e.g., diameter at breast height, total height) incorporated as independent variables in allometric equations must be directly measured in the field applying established best practices, such as those found in:

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

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

Measurement protocols must be detailed in standard operating procedures. Parameter tables for all attributes (e.g., diameter at breast height, total height) incorporated as independent variables in allometric

	equations must be included in the project description under “Data and Parameters Monitored.”
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	To be determined by the project proponent and outlined in standard operating procedures governing field data collection
Purpose of data	Calculation of project emissions using the census-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	Note that where Where a sampled live planting unit is less than the pre-determined size (e.g., minimum diameter at breast height) threshold, it is assigned a value of zero and included in the sample dataset.

Data/Parameter	$DM_{WP-herb,t}$
Data unit	t d.m./ha
Description	Average non-woody biomass in the project scenario in year t
Equations	(9)
Source of data	Field measurements
Description of measurement methods and procedures to be applied	<p>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.</p> <p>Sample measurements must:</p> <ol style="list-style-type: none"> 1) Be demonstrated to be unbiased and derived from representative sampling; and 2) Ensure accuracy through adherence to best practices and quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection). <p>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</p>

	calculated from at least two samples representing the minimum and maximum standing stocks. Alternatively, a conservative estimate of the pool may be determined from a sample taken at the time of minimum standing stock.
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	Note that where Where subsampling is employed to determine a dry-to-wet mass ratio, uncertainty is calculated by treating the sample as a double sample (see parameter $U_{p,t}$).

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

Data/Parameter	$U_{p,t}$
Data unit	Percent%
Description	Percentage uncertainty (expressed as 90-percent% confidence interval as a percentage of the mean) in carbon stock estimate of pool p in the project scenario in year t
Equations	(27), (30) -(28)
Source of data	Calculations from sampled field measurements
Description of measurement methods and procedures to be applied	<p>Uncertainty in pools derived from field measurements with 90-percent% confidence interval calculated as the standard error of the averaged plot measurement multiplied by the t value for the 90-percent% confidence level.</p> <p>Where double or two-phase sampling approaches are employed for aboveground woody biomass, parameter $U_{p=woody,t}$ is represented by error in the relationship (ratio or regression) between the auxiliary variable and woody biomass, referencing the 90-percent% confidence interval of the ratio or 1.645 times the root mean squared error of the regression. Sample error in the auxiliary variable is not treated, because it must be subject to a complete census (see parameter table for $C_{WP-woody-AB,t}$ above).</p> <p>Where double or two-phase sampling approaches are employed for non-woody biomass and/or litter (i.e., where subsampling is employed to estimate the dry-to-green weight ratio that is then applied to a sample estimate of green weight $W_{g,t}$, see parameter tables for $DM_{WP-herb,t}$ and $DM_{WP-L,t}$), parameters $U_{p=non-woody,t}$ and $U_{p=litter,t}$ are calculated by propagating sample error of the green weight estimate and sample error of the estimate of dry-to-green weight ratio.</p>
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	See “Description of measurement methods and procedures to be applied”
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Calculation method	Confidence interval calculated by applying unbiased estimators appropriate to sample design. For examples, see Cochran, W.G. (1977). <i>Sampling techniques</i> . John Wiley & Sons.
Comments	For the area-based quantification approach, pools p include woody biomass, non-woody biomass, dead wood, litter, and SOC.

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

Data/Parameter	$M_{wp,SF,t}$
Data unit	t fertilizer
Description	Mass of N-containing synthetic fertilizer applied in the project scenario in the monitoring interval ending in year t
Equations	(22)
Source of data	Mass of synthetic fertilizer applied in the project, as recorded in land management records

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

Data/Parameter	$M_{wp,OF,t}$
Data unit	t fertilizer
Description	Mass of N-containing organic fertilizer applied in the project scenario in the monitoring interval ending in year t
Equations	(23)
Source of data	Mass of organic synthetic fertilizer applied in the project, as recorded in land management records.
Description of measurement methods and procedures to be applied	Information is monitored via direct consultation with, and substantiated with a written attestation from, a local land manager.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Any quantitative information (e.g., discrete or continuous numeric variables) on management practices must be supported by one or more forms of documented evidence pertaining to the project and relevant monitoring period (e.g., management logs, receipts or invoices).

Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches-
Calculation method	Not calculated
Comments	None

Data/Parameter	$NC_{wp,SF,t}$
Data unit	t N/t fertilizer
Description	N content of synthetic fertilizer applied in the project in year t
Equations	(22)(21)
Source of data	N content is determined following fertilizer manufacturer's specifications.
Description of measurement methods 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 using the census-based and/or area-based quantification approaches
Calculation method	Not calculated
Comments	None

Data/Parameter	$NC_{wp,OF,t}$
Data unit	t N/t fertilizer
Description	N content of organic fertilizer applied in the project in year t

Equations	(23)
Source of data	Published or peer-reviewed data must be used, with preference for more recent data from the <u>country in which the project country is located</u> .
Description of measurement methods and procedures to be applied	Not directly measured
Frequency of monitoring/recording	Monitoring must be conducted at least every five years or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Data referenced must be published or peer-reviewed.
Purpose of data	Calculation of project emissions using the census-based and/or area-based quantification approaches
Calculation method	Not calculated
Comments	None

Data/Parameter	$B_{SDW,t}$
Data unit	t d.m./ha
Description	Average biomass of standing dead wood in year t
Equations	(11)
Source of data	Field measurements
Description of measurement methods and procedures to be applied	<p>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.</p> <p>Sample measurements must:</p> <ol style="list-style-type: none"> 1) Be demonstrated to be unbiased and derived from representative sampling; 2) Ensure accuracy through adherence to best practices and quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection); and 3) Apply fixed size thresholds.

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

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

- a) Equations specific to the forest type within the same ecoregion (defined at the biome level⁴⁵ following [Olson et al., 2001](#)) or Holdridge (1967) life-zone⁴⁶) as the region in which the project is located, or
- b) Global equations specific to the forest type.

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

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

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

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

Attributes (e.g., diameter at breast height, total height) incorporated as independent variables in allometric equations must be directly measured in the field applying established best practices, such as those found in:

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

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

Measurement protocols must be detailed in standard operating procedures. Parameter tables for all attributes (e.g., diameter at breast

⁴⁵ <https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world?https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world>

⁴⁶ http://iridl.ldeo.columbia.edu/SOURCES/_ECOSYSTEMS/_Holdridge/present+.life-zone/downloadsGeoTiff.html

	<p>height, total height) incorporated as independent variables in allometric equations must be included in the project description under “Data and Parameters Monitored.”</p> <p>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).</p>
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	See “Description of measurement methods and procedures to be applied”
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	None

Data/Parameter	$B_{LDW,t}$
Data unit	t d.m./ha
Description	Average biomass of lying dead wood in year t
Equations	(11)
Source of data	Field measurements
Description of measurement methods and procedures to be applied	<p>Lying dead wood is sampled via line intersect sampling (Van Wagner, 1968; Warren and Olsen, 1964), perpendicular distance sampling (Ducey et al., 2013; Williams and Gove, 2003; Williams et al., 2005) or other un-biased approaches. Stratification may be employed to improve precision but is not required. Sample design need not be held constant across all monitoring and verification events.</p> <p>Sample measurements must:</p> <ol style="list-style-type: none"> 1) Be demonstrated to be unbiased and derived from representative sampling; 2) Ensure accuracy through adherence to best practices and quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in

	<p>standard operating procedures governing field data collection); and</p> <p>3) Apply fixed size thresholds.</p> <p>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.</p> <p>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).</p>
Frequency of monitoring/recording	Every five years or more frequently
QA/QC procedures to be applied	See “Description of measurement methods and procedures to be applied”
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	None

Data/Parameter	$DM_{WP-L,t}$
Data unit	t d.m./ha
Description	Average litter dry mass per hectare in the project scenario in year t
Equations	(13)
Source of data	Field measurements
Description of measurement methods and procedures to be applied	<p>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.</p> <p>Litter (dead organic surface material of less than 10 cm diameter) is collected from within fixed-area sampling frames, harvested at ground level and dried at 70 °C to a constant weight to determine dry weight biomass. In cases where sample bulk is excessive, the green weight of the total sample and of a representative sub-sample are recorded in the</p>

	<p>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.</p> <p>Further guidance is provided in the IPCC (2003) <i>Good Practice Guidance for Land-Use, Land-Use Change and Forestry</i> (GPG-LULUCF).</p>
Frequency of monitoring/recording	At $t = 0$ and subsequently every five years or more frequently
QA/QC procedures to be applied	Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QC procedures available from published hand-books, such as those published by FAO and available on the FAO Soils Portal ¹⁷ or from the IPCC (2003) GPG LULUCF is recommended.
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	Note that where Where subsampling is employed to determine a dry-to-green weight ratio, uncertainty is calculated by treating the sample as a double sample (see parameter $U_{p,t}$).

Data/Parameter	$C_{WP-SOC,t}$
Data unit	t C/ha
Description	Average soil organic carbon (SOC) stock in year t
Equations	(14)
Source of data	Field measurements
Description of measurement methods and procedures to be applied	<p>Measured SOC must be determined from samples collected from sample plots located within the project area. Stratification maymust be employed to improve precision but is not required. Sample. The sample design need notshould be held constant across all monitoring and verification events <u>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.</u></p>

¹⁷ Available at: <http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/>

	<p>All organic material (e.g., living plants, litter) must be cleared from the soil surface prior to soil sampling. Soil must be sampled to a minimum depth of 30 cm. SOC stocks must be estimated from measurements of both SOC content and bulk density taken at the same time.</p> <p>Estimates generated must:</p> <ol style="list-style-type: none"> 1) Be demonstrated to be unbiased and derived from representative sampling; and 2) Ensure accuracy through employment of quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in the monitoring plan). <p>Soil sampling must follow established best practices, such as those found in:</p> <p>Cline, M. G. (1944). Principles of soil sampling. <i>Soil Science</i>, 58(4), 275–288.</p> <p>Petersen, R. G., & Calvin, L. D. (1986). Sampling. In A. Klute (Ed.), <i>Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods</i>. Soil Science Society of America and American Society of Agronomy.</p> <p>Re-measurement of soil carbon (after $t = 0$) must use equivalent soil mass procedures (see Wendt & Hauser, 2013).</p> <p>Determination of percent SOC must follow established laboratory procedures, such as those found in:</p> <p>Nelson, D. W., & Sommers, L. E. (1996). Total carbon, organic carbon, and organic matter. In A. L. Page et al. (Eds.) <i>Methods of Soil Analysis: Part 3 Chemical methods</i>. American Society of Agronomy and Soil Science Society of America.</p> <p>Schumacher, B. A. (2002). <i>Methods for the determination of total organic carbon (TOC) in soils and sediments</i>. U.S. Environmental Protection Agency, EPA/600/R-02/069 (NTIS PB2003-100822), or other regionally appropriate sources such as the European Environment Agency.</p> <p>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.”</p>
Frequency of monitoring/recording	<p>At time $t = 0$ and subsequently at every verification (every five years or more frequently).</p> <p>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):</p>

	<p>a)1) Occurs no more than once during the project crediting period (i.e., at site preparation); or</p> <p>b)2) Does not involve soil inversion to a depth exceeding 25 cm (e.g., that would result from a moldboard plow).</p>
QA/QC procedures to be applied	Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QC procedures available from published hand-books, such as those published by FAO and available on the FAO Soils Portal ¹⁸ or from the IPCC (2003) GPG LULUCF is recommended.
Purpose of data	Calculation of project emissions using the area-based quantification approach
Calculation method	Calculated as the average of sample measurements
Comments	None

9.3 Description of the Monitoring Plan

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

- 1) Specification of the quantification approach applied (area-based or census-based). Where using the census-based approach, clearly define the planting unit. If using the area-based approach, see procedures below in Section 9.3.1;
- 2) A description of each monitoring task to be undertaken, and the technical requirements therein;
- 3) Definition of the accounting boundary. Where area-based and census-based quantification approaches are used in the same project, the monitoring plan must specify the spatial accounting boundary for the area-based approach, and demonstrate non-overlap with the census-based approach (applying area specifications detailed in Section 5);
- 4) Parameters to be measured, including parameter tables for all directly measured woody plant attributes (e.g., diameter at breast height, total height) incorporated as independent variables in allometric equations;

¹⁸ <http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/>

- 5) Data to be collected and data collection techniques, including data used in monitoring of the performance benchmark, documented in a standard operating procedure for field data collection. Sample designs must be specified (clearly delineate the sample population, justify sampling intensities, selection of sample units, and sampling stages, where applicable) and un-biased estimators of population parameters identified that are applied in calculations;
- 6) Anticipated frequency of monitoring for each variable;
- 7) Quality assurance and quality control (QA/QC) procedures to ensure accurate data collection and to screen for, and where necessary, correct anomalous values, ensure completeness, perform independent checks on analysis results, and other safeguards as appropriate;
- 8) Data archiving procedures, including procedures for any anticipated updates to electronic file formats. All data collected as a part of the monitoring process, including QA/QC data, must be archived electronically and kept for at least two years after the end of the last project crediting period;
- 9) Roles, responsibilities, and capacity of the monitoring team and management. Roles and responsibilities defined for chain of custody, repositing and maintenance of all data;
- 10) ~~The monitoring plan must also specify the~~Specific schedule and procedures for periodically acquiring, archiving, and processing remote sensing data to derive stocking indices; and
- 11) A full description of the stocking index, and the process to derive it (reference to the database is insufficient).

9.3.1 Database Requirements for Project and Control Plots

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

- 1) A description of the stocking index and the process to derive it;
- 2) A list of project plots including unique IDs, locations, size and configuration, and time series of stocking index values from time $t = 0$ to time t .
- 3) A list of control plots including unique IDs (referencing unique ID of corresponding project plot to which they are matched), locations, size and configuration, weights, and time series of stocking index values from time $t = 0$ to time t ; and
- 4) Remote sensing datasets and time stamps used to derive stocking index values.

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APPENDIX 1: PERFORMANCE METHOD

10.1 A1.1 Applicability Conditions

This appendix is applicable under the following conditions:

- 1) The project meets all applicability conditions detailed in Section 4 of this methodology;
- 2) The project activities will produce continuous vegetative cover on any contiguous area exceeding one hectare allowing for clear spatial delineation of the project area; and
- 3) The project's performance benchmark must be updated at each verification or every five years, whichever comes first.

10.2 A1.2 Baseline Scenario

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

The business-as-usual changes in vegetation cover are represented by the performance benchmark, which is equal to the ratio of average change in stocking index, SI, of control plots to project plots. The control plots are appropriately matched to the project area based on similar biophysical, social, and political conditions, and historic stock trends (see below, 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 ~~that~~ all project and control plots referenced in ~~the~~ this appendix are remotely sensed and will therefore be referred to as “project plots” and “control plots” from here forward in Appendix 1.

10.3 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. Equation ~~(A4)~~ (A6) derives the performance benchmark for both demonstration of additionality and the crediting baseline. Equation (30) applies the performance benchmark for the crediting baseline. A performance benchmark is developed for each project area, or in the case of grouped projects, a separate performance benchmark is developed for each annual

cohort of instances. Performance benchmarks are monitored ex-post, hence are dynamic. The approach to select control plots outlined below constitutes a matching approach widely used in impact evaluation in the environmental field (Ferraro & Hanauer, 2014). Matching approaches are not expected to produce exact matches for individual land parcels, but rather to produce robust estimates of impact for sample “populations” of matched pairs (controls and treatments).

An ex-ante estimate of the performance benchmark must be calculated referencing a value of $\frac{\Delta SI_{control,t}}{\Delta SI_{control,t}}$ using the stocking indices for the historic period $t = -10$ to $t = 0$ for the selected control plots (derived in [Step 2 above](#)); [Section 10.4](#)). The project slope is derived from the growth and yield curve procedure provided in [Section 8.2.9 of the methodology](#) ex-ante calculations (see [Section 8.6](#)).

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

10.4 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](#) [Section 9.2 of the methodology.](#)

Overview of ~~Establishing~~ [establishing the Performance Benchmark](#) ~~performance benchmark~~:

- 1) Starting at time $t = 0$, or at time $t > 0$ where initial stock measurements occurred after the project start date. ~~Select, select~~ project plots via representative sampling.
- 2) For each project plot, select matched control plots:
 - a) Delineate the donor pool using maps of categorical variables matching the project plot.
 - b) Evaluate continuous matching covariates (including the historical trend in stocking index) on prospective control plots.
 - c) Select k control plots most closely matching the project plot.
- 3) For the sample population of matched project and control plots, evaluate match quality and finalize matching.

Assessment of ~~the Performance Benchmark~~ [performance benchmark](#) at each monitoring event:

- ~~1)4)~~ [_____](#) Monitor stocking index on project and control plots.
- ~~2)5)~~ [_____](#) Derive slopes for accumulated time series (from time $t = 0$ to time t) of stocking indices estimated across the sample populations of project and control plots.

3)6) Calculate performance benchmark.

Step 1: Select ~~project plots~~ **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 0.09 hectares (30 × 30 m) to 10 hectares ~~in area~~. At least ~~75 percent~~ of each unit must be within the project area boundary. Project plots may be represented by individual pixels or aggregates of pixels.
- 2) Select a representative sample of $n = 30$ or more project plots, via random or systematic, stratified, or ~~un-stratified~~ unstratified sampling.

Step 2: Select ~~control plots~~ **Control Plots** for ~~each project plot~~ **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 resolution no coarser than 30 ~~×~~ 30 meters.

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

Factor	Procedure and data source (GIS layer)
Jurisdictional boundary	Where the project area is within a subnational jurisdiction either registered under Jurisdictional and Nested REDD+ (JNR) or delineated by the national or subnational government for reporting REDD+ (e.g., delineated as a discrete Forest Reference Emission Level), the relevant jurisdictional boundary is the subnational jurisdiction (no lower than the second administrative level from the national level). Otherwise, the jurisdictional boundary used is the national boundary. Source: the GIS layer for the jurisdictional boundary must be from a published or official national government source.
Ecoregion	The donor pool area must exclude any areas not within the same ecoregion (biome level) as the project.
Policy environment	The donor pool area must exclude any areas of the jurisdictional boundary (defined above) with presence/absence of any operating <u>national or</u> subnational government-funded <u>policy/</u> program providing incentives for tree planting that differs from <u>that in</u> the project area: <u>(e.g., USDA Conservation Reserve Program)</u>

Factor	Procedure and data source (GIS layer)
	<p>Operating government-funded program providing incentives for tree planting</p> <p>A currently (as of the relevant evaluation date) funded and implemented national or sub-national government policy/program providing monetary incentives for tree planting (e.g., USDA Conservation Reserve Program)</p>
Outside any registered AFOLU project	<p>Optionally, and as available, the donor pool area may exclude boundaries of any AFOLU projects registered under a carbon offset program.</p> <p>Source: kml files from project registries (e.g., Verra registryRegistry)</p>
Land tenure	<p>All land tenure classifications present in the project area must be represented in the donor pool.</p> <p>Exclude any areas with different land tenure classification than the project area. Land tenure classification should be sourced from published or official government sources.</p> <p>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.</p> <p>Source: published or official government source</p>
Distance from project plot	Exclude areas beyond a 100 km radius of the centroid of the project plot.

2) ~~2)~~ Evaluate project plots:

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

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

- i) ~~between~~Between $t = -10$ and $t = -8$
- ii) ~~between~~Between $t = -8$ and $t = -1$
- iii) ~~at~~At $t = 0$

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

Matching covariate	Description
$SI_{t=0}$, $SI_{t=-10}$, etc.	Stocking indices from three or more time points during the historic period spanning 8–10 years immediately prior to the project start date, minimally

including values for the beginning of the historic period (not before $t = -10$ and no later than $t = -8$) and for time $t = 0$.

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

3) ~~3)~~ Select control plots:

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

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

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

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~~ Match Quality and ~~finalize matching~~ Finalize Matching

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

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

$$SDM = \frac{ABS(\bar{x}_{wp,x} - \bar{x}_{bsl,x})}{\sqrt{\frac{\sigma_{wp,x}^2 + \sigma_{bsl,x}^2}{2}}} \quad (A2)$$

$$= \frac{|\bar{x}_{wp,x} - \bar{x}_{bsl,x}|}{\sqrt{\frac{\sigma_{wp,x}^2 + \sigma_{bsl,x}^2}{2}}}$$

Where:

SDM	= Standardized difference of means
$\bar{x}_{wp,x}$	= Mean value of covariate x in the population of project plots
$\bar{x}_{bsl,x}$	= Mean value of weighted sums of covariate x in the population of matched sets of control plots
$\sigma_{wp,x}^2$	= Standard deviation of covariate x in the population of project plots
$\sigma_{bsl,x}^2$	= Standard <u>Weighted standard</u> deviation of covariate x in the population of control plots

Overall match results are deemed valid where SDM for each covariate is less than or equal to 0.25.

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

- Progressively expanding the radius of the donor pool in 100 km increments, and/or
- Decreasing the k value for all project plots, until a valid overall match is achieved.

Step 4: Monitor ~~control~~ Control and ~~project plots~~ 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:

- 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
- 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~~ Evaluate Slopes for ~~time series~~ Time Series of ~~stocking indices~~ Stocking Indices

Assemble accumulated time series of $\Delta SI_{control,t}$ and $\Delta SI_{wp,t}$ values from time $t = 0$ to time t , estimated across the sample populations of project and control plots. The derivation of SI for the monitoring interval must include at minimum three time steps: t , $t - 1$, and at least one time point between t and $t - 1$.

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

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

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

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

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 ~~matched~~ control plots (i,j) with values assessed at time t

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

$$W_{wp,i,t} = \frac{1}{\sum_{t=0}^t n_{rs_t}} \quad (A4)$$

Where:

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

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

$$Z = \frac{\Delta SI_{wp,t} - \Delta SI_{control,t}}{\sqrt{SE_{\Delta SI_{wp,t}}^2 + SE_{\Delta SI_{control,t}}^2}} \quad (A5)$$

Where:

- Z = Z value (unitless)
- $\Delta SI_{control,t}$ = Average annual increase (slope) in stocking index SI in control plots through time t
- $\Delta SI_{wp,t}$ = Average annual increase (slope) in stocking index SI in project plots through time t

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

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

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

Step 6: Derive performance benchmark

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

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

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

Where:

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

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

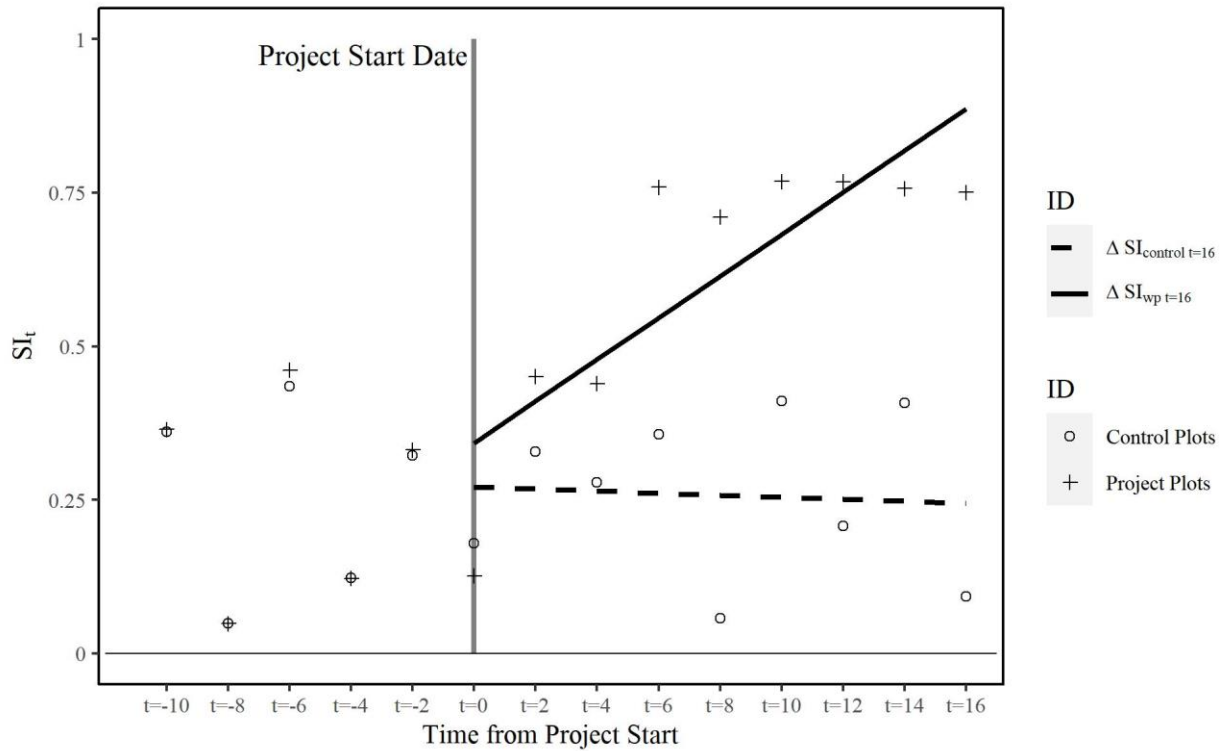
T	Control plot i,j	$W_{control,i,j,t=0}$	$SI_{control,i,j,t}$	$W_{control,i,j,t=5}$
0	1_1	0.20	0.08	0.10
0	1_2	0.17	0.04	0.08
0	1_3	0.14	0.01	0.07
0	1_4	0.11	0.04	0.06
0	1_5	0.09	0.06	0.05
0	1_6	0.09	0.00	0.04
0	1_7	0.08	0.02	0.04

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

T=5 evaluation

T	Project plot i	$W_{wp,i,t}$	$SI_{wp,i,t}$
0	1	<u>±0.5</u>	0.05
5	1	<u>0.5</u>	0.80
		$\Delta SI_{wp,t=5}$	0.15
		PB_t	13%

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



Example 2: Simplified performance benchmark over time with one project plot and one matched control plot

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

12	0.60	0.05		12	0.01	0.00	3
13	0.63	0.05		13	0.02	0.00	3
14	0.67	0.05		14	0.03	0.00	3
15	0.70	0.05		15	0.00	0.00	3
16	0.72	0.05		16	0.00	0.00	2
17	0.75	0.05		17	0.01	0.00	2
18	0.77	0.05		18	0.02	0.00	2
19	0.79	0.05		19	0.03	0.00	3
20	0.81	0.05		20	0.00	0.00	2

10.5 A1.5 Data and Parameters Monitored

Data/Parameter	$SI_{control,t}$ and $SI_{wp,t}$
Data unit	Unspecified
Description	Stocking index in scenario (-control plot j or project plot i) at time t
Equations	(A5)
Source of data	<p>SI is an unspecified remote sensing metric that has with demonstrated correlation with terrestrial aboveground carbon stocks (e.g., normalized difference fraction index¹⁹ from Landsat imagery, average canopy height derived from LiDAR or percentage canopy cover interpreted from aerial imagery).</p> <p>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). TargetThe 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.</p> <p>Spatial scale: Divide the entire project area into <u>equal-sized</u> polygons from 0.09 hectares (30 × 30 m) to 10 hectares in area. Polygons must be of equal size with at least 75 percent% of each polygon <u>must be</u> located within the project</p>

¹⁹ Souza Jr, C. M., Roberts, D. A., ~~and~~ & Cochrane, M. A. (2005). Combining spectral and spatial information to map canopy damage from selective logging and forest fires. *Remote Sensing of Environment*, 98(2-3):329–343. <https://doi.org/10.1016/j.rse.2005.07.013>, 329–343. <https://doi.org/10.1016/j.rse.2005.07.013>

	area boundary. project Project plots may be represented by individual pixels or aggregates of pixels.
Description of measurement methods and procedures to be applied	
Frequency of monitoring/recording	At least annually
QA/QC procedures to be applied	<p>The remote sensing metric applied must <u>be</u>:</p> <ol style="list-style-type: none"> 1) Have significant correlationSignificantly <u>correlated</u> with terrestrial carbon stocks, at least with aboveground biomass, that has been as previously substantiated with<u>demonstrated in</u> published or peer-reviewed studies; <u>and</u> 2) Be validated<u>Validated</u> with direct measurements from the project region (collected from within the project ecoregion; ecoregion defined at the biome level²⁰ <u>following Olson et al., 2001</u>). <p>Processing and analysis of remote sensing data must apply established best practices, such as those found in:</p> <p>Global Forest Observations Initiative (2016). <i>Integration of remote-sensing and ground-based observations for estimation of emissions and removals of greenhouse gases in forests: Methods and guidance from the Global Forest Observations Initiative, edition 2.0</i>. <u>U.N.</u> Food and Agriculture Organization.²¹</p> <p>Mitchell, A. L., Rosenqvist, A., & Mora, B. (2017). Current remote sensing approaches to monitoring forest degradation in support of countries measurement, reporting and verification (MRV) systems for REDD+. <i>Carbon Balance and Management</i>, 12, 9.²² <u>Article 9.</u> https://doi.org/10.1186/s13021-017-0078-9</p>
Purpose of data	Selection of control plots and derivation of performance benchmark for the area-based approach
Calculation method	

²⁰ <https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world>

²¹ Available at:

<https://www.fs.usda.gov/research/treesearch/56461>; https://www.fs.fed.us/rm/pubs_journals/2020/rmrs_2020_espejo_a001.pdf

²² <https://cbmjournal.biomedcentral.com/articles/10.1186/s13021-017-0078-9>

Comments

Note that SI may be derived using different remote sensing metrics for the selection of control plots and for monitoring the performance benchmark. It is expected that the same remote sensing technology may not be available for both the historical analysis (selection of control plots) and monitoring ex-post.

The same remote sensing metric must be used for monitoring SI ex-post in both control plots and project sample plots. Where more accurate remote sensing metrics become available over time, the remote sensing metric used for monitoring SI ex-post may be changed when all of the following apply:

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

2)b) ~~It is possible to harmonize the~~ The new metric can be harmonized with the previous metric, applying procedures from peer-reviewed literature²³ to ensure data continuity and remove sources of misalignment (e.g., geometric, radiometric, and/or spectral artifacts) introduced by the new metric; and

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 within an overlap interval of ~~not less than~~ at least two years, or as prescribed by the procedure.

3) The location of all stocking index project and control plots must be included in the project description.

²³ e.g., For example <https://www.usgs.gov/landsat-missions/harmonizing-landsat-archive>

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

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

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

$$RC_{Es} = \frac{Es}{\sum_{s=1}^S Es} \quad (A7)$$

Where:

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

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

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

The GHG emissions, possible decreases in carbon pools, and leakage emissions ~~not included in~~excluded from the summation are considered insignificant where their sum is lower than ~~five-percent~~5% of carbon dioxide removals. Otherwise, the procedure described above must be continued beyond the threshold of 0.95 until ~~the above~~this condition is met.

DOCUMENT HISTORY

Version	Date	Changes
v1.0	28 Sep 2023	Initial version released
<u>v1.1</u> <u>Draft</u>	<u>22 May 2024</u>	<ul style="list-style-type: none">• <u>Updated references and numbering</u>• <u>Clarified the extent of georeferencing associated with the census-based method</u>• <u>Clarified how to account for clearing of a degraded ecosystem for site preparation</u>• <u>General copyediting</u>