ASES ON-CHAIN PROTOCOL

METHODOLOGY FOR ESTIMATING CARBON REMOVALS AND STORAGE IN VEGETATION

IV. Methodologies V1.0

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On-Chain Protocol

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INTRODUCTION

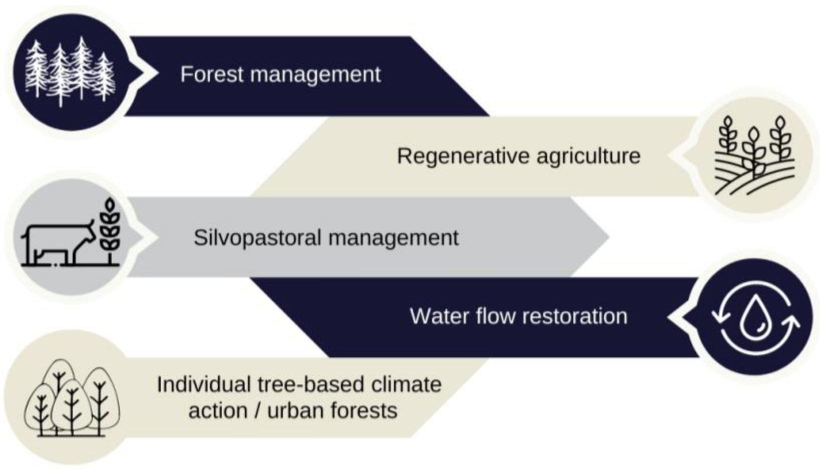
This methodology stipulates an annual field visit to verify survival of planted trees and shrubs, as well as to perform measurements necessary for the calculation of above- and below-ground biomass, as well as trimestral desk monitoring through satellite and/or drone images in order to verify regularly the continuity of the project and that issued VCCs are linked to real GHG emissions removals.

I. DEFINITIONS

- **Aboveground biomass**: Is the dry mass of live or dead matter from living organisms that stands above the ground, expressed in terms of mass per unit area.
- **Survival and mortality** The finite survival rate is defined as the number of individuals alive at the end of the census period, divided by the number of individuals alive at the beginning. Finite mortality rate is defined as 1.0—finite survival rate. Values of both survival and mortality rate always relate to some specific time period (Krebs 1999).
- **Carbon Pools** A system that has the capacity to store or release carbon 1, including above-ground biomass, below-ground biomass, litter, dead wood and soil organic carbon.
- **Forest carbon sources.** Forests are considered sources when they emit more than they remove. Forests emit carbon through respiration and decay when disturbances (harvesting, fires, insects, storms, droughts and floods) occur.

II. APPLICABILITY CONDITIONS

a) The type of Project is:



b) The Project complies with the standards of the aOCP Program;
c) The Project was developed less than 24 months ago;
d) The Project area has not been degraded, deforested or burned in the last 24 months;

e) If a project area does not meet requirement "d" the project proponent must offer a technical reason arguing that ecological restoration is necessary because the area's biodiversity and environmental services are vulnerable.

III. METHODOLOGICAL CONSIDERATIONS

III.1. APPLICATION OF METHODOLOGY

The following table identifies the types of projects that should use the Methodology for estimating carbon removals and storage in vegetation, which correspond to those that lead to an increase in vegetation biomass, either by directly planting trees and shrubs, or indirectly by enhancing natural forest or grassland regeneration.

TABLE 1. APPLICATION OF METHODOLOGY BY PROJECT TYPE

Type of project	Use of methodologies			
	Carbon in vegetation	Carbon in soil	Biodiversity	Water
Regenerative agriculture	✓			
Forest management	✓			
Silvopastoral	✓			
Urban forest	✓			
Water restoration	✓			

III.2. METHODOLOGY PARAMETERS

The methodology's parameters and the factors that will be taken into account when using it are listed in the following table:

III.2.1. CARBON POOLS AND SOURCES OF GHG EMISSIONS

Table 2 and 3 below identify the carbon pools included or excluded from the project boundary.

TABLE 2. SELECTED CARBON POOLS UNDER BASELINE AND PROJECT ACTIVITY

Carbon Pools	Included	Explanation
Aboveground woody biomass	✓	Major pool considered in the project scenario

Carbon Pools	Included	Explanation
Aboveground non-woody biomass	✓	The carbon stock in this pool is expected to increase as a result of the implementation of the project
Belowground biomass (to a depth of 30cm), refers to the root systems of the vegetation cover	✓	The carbon stock in this pool is expected to increase as a result of the implementation of the project
Deadwood	*	Carbon stock in these pools may increase due to implementation of the project activity
Litter	*	Carbon stock in these pools may increase due to implementation of the project activity
Soil Organic Carbon (SOC)	✗	aOCP provide a methodology specific for SOC to use in case Project Activities have a significant impact on this reservoir.

(*) Optional

TABLE 3. GHG SOURCES INCLUDED IN OR EXCLUDED FROM THE PROJECT BOUNDARY

Source		Gas	Included	Explanation
Baseline	Aboveground biomass	CO_2	✓	Major pool considered in the baseline scenario
		CH_4	✗	Conservatively excluded
		N_2O	✗	Conservatively excluded
	Belowground biomass	CO_2	✓	Major pool considered in the baseline scenario
		CH_4	✗	Conservatively excluded
		N_2O	✗	Conservatively excluded
Project	Aboveground biomass	CO_2	✓	Major pool considered in the baseline scenario
		CH_4	✗	Conservatively excluded
		N_2O	✗	Conservatively excluded
		CO_2	✓	Major pool considered in the baseline scenario

Source		Gas	Included	Explanation
	Belowground biomass	CH_4	✗	Conservatively excluded
		N_2O	✗	Conservatively excluded

TABLE 4. PARAMETERS OF THE METHODOLOGY

Parameters	Description
Number of trees of each species planted	Each tree and shrub planted shall be georeferenced, including the species name in the database.
Age of the plants	Refers to the time elapsed between the date of plantation and the date of monitoring.
Survival rate	Percentage of the planted trees and shrubs that are still alive at the moment of counting.
NDVI	Normalized Difference Vegetation Index
DBH	Diameter at breast height (at 130 cm from the ground)

III.2.2. DATA COLLECTION

aOCP considers 2 phases of the project development, for which different methodologies will be used. The methodology to be used for the estimation of above- and below-ground biomass, and ultimately of carbon is determined by the age of the project.

- **From Years 0 to 5,**

In this phase, plants are developing a robust root system that will allow them to settle and survive, the shoots are too thin to be measured in field and with aerial images, additionally, mortality rate is higher than at latter stages. For this reason, biomass will be retrieved from species-specific growth tables consulted from the literature in function of the plants' age. A yearly field survey shall be performed in order to monitor survival/mortality. Knowing the (theoretical) biomass of each species at the moment of monitoring, the number of individuals of each species and the survival rate, allows the calculation of the total biomass by using the formula:

$$B_T = \sum_{i=1}^{s} B_{ia} n_i S_i$$

Where:

B_T = total biomass (kg C or g C)

B_{ia} = biomass of species *i* at age *a* (kg C or g C)

n_i = number of individuals of species *i*

S_i = survival rate of species *i* (from 0-1)

Because aOCP's credit issuance system allows the biannual issuance of VCCs, survival shall be monitored and verified also in a biannual basis by means of remote sensing techniques, as follows. Survival will be monitored yearly and reported mortality will be the basis for replacement and maintenance.

Before and after the establishment of the project , Sentinel-2 and/or drone images will be used to assess the differences in land cover, landscape and spectral response through optical images, band composites and indices (eg. NDVI). Table 3 provides a list of remote sensing datasets that can be used to make a more robust analysis.

The NDVI over the project area is computed with one image per month (ideally the one with the lowest cloud percentage). The number of trees/shrubs represented on each pixel depends on the spatial resolution of the images used. The Sentinel-2 mission provides the globally available and open source satellite images with highest spatial resolution (10 m). One pixel of this dimension can cover a high number of trees (for instance 60 trees in a Miyawaki forest). The changes of NDVI through time reflect the conditions of the trees grouped by pixels. The state of the plantation can be inferred by comparing the changes of each single pixel through time and the evolution of each pixel with respect to others. This changes will be taken into account by ASES for adjusting the biomass calculation. A pixel with an NDVI increase lower than others might indicate lower plant development.

NDVI will also be used as evidence for the project's first assessment, right after the soil management and planting activities take place and contrasting it with the pre-project conditions (baseline scenario).

- **From Year 6 until the end of the project**

From the 6th year, inventory plots will be established within the project polygon(s), representing all types of land cover and land use present, and the following parameters will be obtained: area (ha), number of plots, number of trees, DBH (cm), height (m), density (stems/ha), number of species planted, land cover types present and their percentage (type and %). They size of the plots will be established based on standard guidelines for inventories according the ecosystem type and the number of plots will be enough to assess 25% of the total project area, distributed proportionally to the area of each land cover type. DBH of all living trees within the plot will be measured at 1.3 m above the ground level to the nearest 0.1 cm using a diameter tape or by measuring the circumference and converting into diameter with the formula

$$\mathbf{D=c/\pi}$$

Where D is diameter, c is the circumference and π is the constant 3.1416.

- **Satellite images**

S-1 data and preprocessing:

S-1 data for the period January to December of the year of interest will be downloaded from the Sentinel data hub (https:// scihub.copernicus.eu/dhus/#/home). The data will be acquired in the Interferometric Wide Swath (IW) mode with dual polarization (VV, VH). The product type is the Multi-Look Ground Range-Detected (GRD). The acquisition incidence angle ranging from 30 deg to 46 deg.

Two pre-processing procedures will be applied to each scene. These are **terrain correction** (with **radiometric normalization**) and **speckle filtering**. ESA's Sentinel Applications Platform (SNAP) software was used for the pre-processing. The Range-Doppler Terrain Correction (RDTC) (Small and Schubert, 2008) module of SNAP shall be used for the **terrain correction**. Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) at 30 m resolution is highly recommended. The backscatter intensities of the dual polarization bands will be converted to sigma nought by applying **radiometric normalization**. The Refined Lee speckle filtering algorithm (Lee and Pottier, 2009) will be subsequently applied to the terrain and radiometrically corrected images to **reduce speckle**. Refined Lee will be selected due to its reported superior performance when compared with other filters in SNAP (Lukin et al., 2018). The backscatter values will be **converted to decibels** using the follow equation:

$$\sigma_0 (dB) = 10 log10 \sigma_0$$

Where:

- σ_0 ***dB*** is the normalized radar cross section and σ_0 is the backscatter for a specific polarization.

In addition to the backscatter values, **the difference (VH-VV) and sum (VH + VV)** of the respective polarization bands (VH, VV) for each month will be computed. Laurin et al. (2018) suggest that with backscatter values expressed in dB scale, the computed difference corresponds to a quotient while the sum can be considered as a product.

S-2 data and preprocessing

S-2 L2A (bottom of atmosphere) data are to be downloaded for the year of study, only for the months in which cloud cover is lower than 10%.

Ten, out of the thirteen **bands** of S-2 (4 visible, 4 red edge, 2 short-wavelength infrared (SWIR)), will be extracted for subsequent pre-processing and analysis. The 20 m bands of S-2 (SWIR and red edge bands) will be resampled to 10 m spatial resolution using the nearest neighbor method, and all the tiles will be subsequently mosaicked.

Three **biophysical parameters** – leaf area index (LAI), fractional vegetation cover (FCOVER) and fraction of photosynthetically active radiation (FAPAR) will be calculated for each image using the “Biophysical Processor” in the SNAP software. These variables have been found to be useful for biomass estimation because they describe the spatial distribution of vegetation state and dynamics (Baret et al., 2013; Dahms et al., 2016). SNAP computes the variables using tested, generic algorithms based on specific radiative transfer models. The main steps involved in the computation are (1) normalization of the inputs, (2) implementation of the artificial neural network (ANN) algorithm and (3) denormalization of the output and (4) generation of quality indicator (Weiss and Baret, 2016).

In addition to the biophysical variables, five **spectral vegetation indices** useful for biomass modeling and estimation will be computed from the S-2 data. Table 3 provides a list of all variables (bands, indices and biophysical parameters) to be used.

TABLE 5. LIST OF S-1 AND S-2 PREDICTORS USED FOR AGB MODELLING

Sensor		Bands, indices or parameters	Definition
Sentinel-1 (monthly: January to December)	Polarization	VV	Vertical transmit-vertical channel
		VH	Vertical transmit-horizontal channel
	Indices	VH-VV (Laurin et al., 2018)	Quotient
		VH+VV (Laurin et al., 2018)	Product
Sentinel-2 (months with cloudiness < 10%)	Multispectral Bands	Band 2	Blue, 490 nm
		Band 3	Green, 560 nm
		Band 4	Red, 665 nm
		Band 5	Red edge, 705 nm
		Band 6	Red edge, 749 nm
		Band 7	Red edge, 783 nm
		Band 8	Near infrared (NIR), 842 nm
		Band 8A	Near infrared (NIR), 865 nm
		Band 11	SWIR-1, 1610 nm
		Band 12	SWIR-2, 2190 nm
	Vegetation indices	NDVI (Rouse et al., 1974)	(Band 8 - Band 4) / (Band 8 + Band 4)
		NDVIre (Forkuor et al., 2020)	(Band 6 - Band 4) / (Band 6 + Band 4)
		STV11 (Thenkabail et al. 1994)	(Band 11 * Band 4) / (Band 8)

Sensor		Bands, indices or parameters	Definition
		STV12 (Thenkabail et al. 1994)	Band 8 / (Band 4 * Band 12)
		STV13 (Thenkabail et al. 1994)	Band 8 / (Band 4 * Band 11)
	Vegetation Biophysical Variables	LAI	Leaf Area Index
		FCOVER	Fraction of Vegetation Cover
		FAPAR	Fraction of Absorbed Photo-synthetically Active Radiation

IV. BASELINE SCENARIO

The baseline scenario of a project activity implemented under this methodology is continuation of the pre-project land use.

As per the applicability conditions, project proponents must demonstrate that the project area has not been deforested in the last 24 months and that the ecosystem of the project area is vulnerable to degradation or perturbation if not preserved or restored. The way to demonstrate this is established in Section IV of the *aOCP Methodology for biodiversity assessment*. Given that biodiversity is a central component of the aOCP, all projects are required to assess it. It is not necessary to repeat the assessment in this methodology if it has been performed following the *aOCP Methodology for biodiversity assessment.*

V. QUANTIFICATION

Before and after the establishment of the project , Sentinel-2 and/or drone images will be used to assess the differences in land cover, landscape and spectral response through optical images, band composites and indices (eg. NDVI).

In order to measure the carbon removals from the Project, the Project Proponent shall calculate biomass convert it to carbon stocks:

- Before the start of the project
- After completing the plantation or soil/forest management works
- At regular intervals until the end of the project.

V.1 STRATIFICATION

If biomass distribution over the project area is not homogeneous, stratification should be carried out to improve the precision of biomass estimation. Different stratifications may be appropriate for the baseline and project scenarios in order to achieve optimal precision of estimation of net GHG removals by sinks. In particular:

- **a)** For baseline net GHG removals by sinks, it is usually sufficient to stratify the area according to major vegetation types and their crown cover and/or land use types;
- **b)** For actual net GHG removals by sinks the stratification for ex ante estimations is based on the project planting/management plan and the stratification for ex post estimations is based on the actual implementation of the project planting/management plan. If natural or anthropogenic impacts (e.g. local fires) or other factors (e.g. soil type) significantly alter the pattern of biomass distribution in the project area, then the ex post stratification is revised accordingly.

V.2 CALCULATION OF BIOMASS STOCKS AT PLOT SCALE

For the first 5 years of the project, biomass was retrieved from the bibliography for each species present and multiplied by the number of individuals of each species. From year 6, when field biometric data will be obtained, AGB will be calculated from species-specific allometric equations, firstly computed for each individual tree and summed by plot. The amount of carbon in biomass will be determined by multiplying it by a factor of 0.5 (Lung and Espira, 2015; (Forkuor et al., 2020).

The basic form of allometric equations is:

$$\mathbf{y = a(DBH)^{b}}.$$

Where *y* is dry biomass, DBH is diameter at 130cm height and *a* and *b* are scaling factors.

They take into account the different components of the biomass (branches and leaves, trunk, total above ground and roots).The values of *a* and *b* vary between species and biomass components. They can be obtained from the literature.

V.3. AGB MODELLING

Figure 1 presents an overview of the methodological approach taken to model AGB in the study area. It entails relating the measured AGB values to the remote sensing variables, i.e. backscatter values from S-1 and spectral information from S-2 (Table 5) through regression. Studies that used optical or SAR data or their combination in AGB mapping confirmed the relationship between spectral and backscatter information on one hand and AGB on the other (Bouvet et al., 2018; Baccini et al., 2008; Le Toan et al., 1992; Vaglio Laurin et al., 2013; Wingate et al., 2018). Four main steps are followed to derive the AGB map: (1) conversion of field data into AGB and carbon stocks, (2) extraction of training and validation data for the regression analysis (3) regression analysis and (4) accuracy assessment.

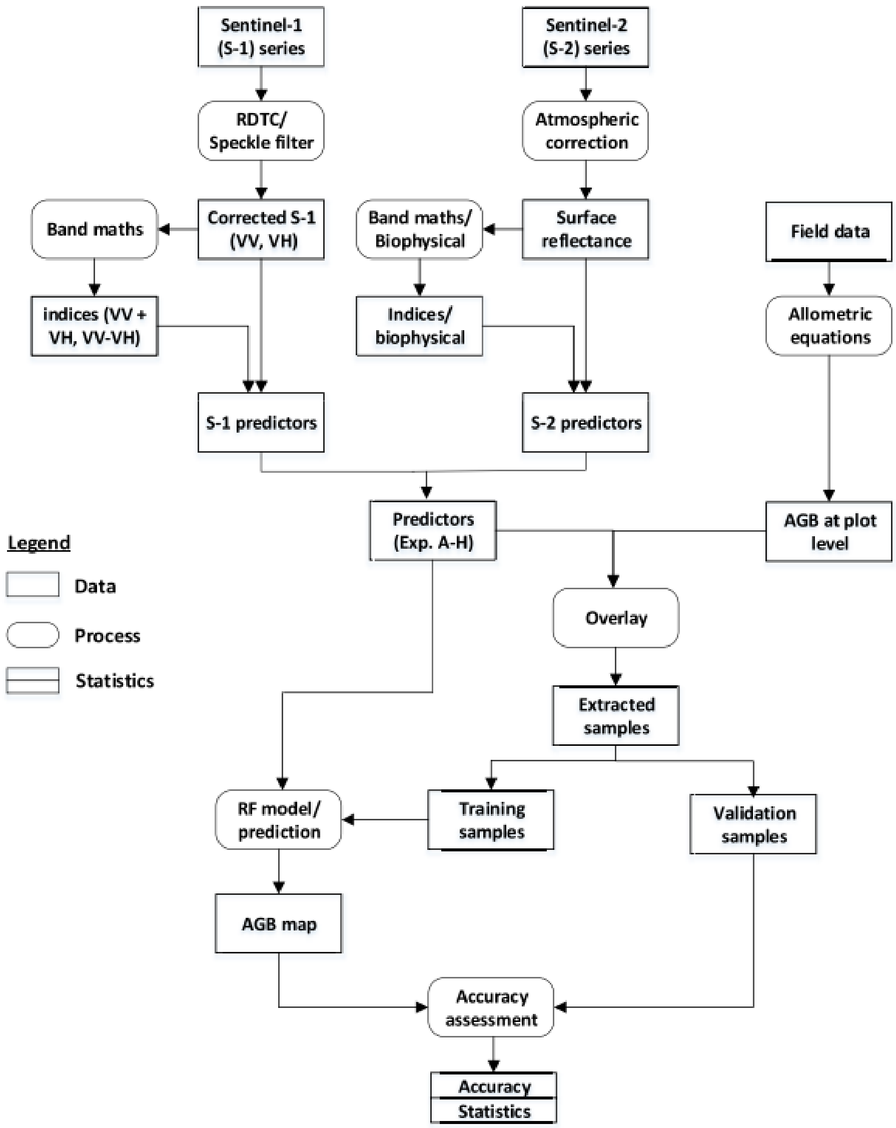


FIGURE 1. OVERVIEW OF METHODOLOGICAL APPROACH. RDTC =RANGE DOPPLER TERRAIN CORRECTION (FORKUOR ET AL., 2020).

TRAINING AND VALIDATION DATA

Training and validation data for the regression analysis will be extracted by overlaying a polygon layer of the forest inventory plots on an image stack of all predictors and extracting the corresponding values.

The predictors to be used, comprise S-2 spectral bands (10 bands each for each monthly image with cloudiness < 10%, the same months will be used for all optical derivates), 5x S-2 spectral indices for each month, 3x S-2 biophysical parameters for each month, radar backscatter bands (2 bands each for the months where cloudiness > 10%, the same months will be used for all backscatter derivates) and 2x radar difference and sum bands for each month. The calculated AGB values will be appended to the extracted spectral and backscatter values. The resulting table/values will be then split into 60-40% training and validation samples using the "createDataPartition" function in the caret (classification and regression training) package (Kuhn et al., 2017) in the R statistical and programming environment (R Core Team, 2017).

RANDOM FORESTS REGRESSION (RFR)

The caret (classification and regression training) package (Kuhn et al., 2017) in the R statistical and programming environment (R Core Team, 2017) was used to implement the RFR (Kuhn et al., 2017). The caret package is recommended due to its ability to streamline the model building and evaluation process of a multitude of algorithms (Kuhn et al., 2017). The package reduces the complexity associated with model tuning by first iterating over a range of values of model parameters and selects the parameter combination that gives the best performance for building a final model. The parameters requiring tuning such as the number of trees to grow in the forest (ntree) and the number of randomly selected predictor variables at each node (mtry) can be set using the grid search method in the "caret" package (Kuhn et al., 2017) and ten-fold cross validation with 5 repetitions.

DATASETS TO BE USED

The data to be used for the random forest regression is 1 image for each month. If there is at least 1 image for the month, with less than 10% of cloudiness, use Sentinel-2 images comprising the spectral bands, vegetation indices and biophysical variables indicated in Table 3. For months in which there is not a single S2 image with cloudiness inferior to 10%, then a Sentinel-1 image should be used, comprising polarization and indices, as indicated in Table 3.

VI. MONITORING

Monitoring considers two aspects: the data and parameters that will be used by the Verifier to review the Project and the temporality in which the activities must be carried out.

VI.1. DATA AND PARAMETERS CONSIDERED IN THE VERIFICATION

The data that will be verified by the aOCP Expert Panel will be the results of the Project's impact on biodiversity in the stages: pre and post activities, as well as the information capture forms on site. The Project Proponent shall take into account the following considerations:

TABLE 6. PARAMETER CONSIDERED IN THE VERIFICATION

Parameter	CO_2 (mass of carbon dioxide, kg or ton)
Description	Carbon emissions removed from the atmosphere through photosynthesis and stored in vegetal biomass.
Equation	CO_2=C * 3.67 C=dry biomass * 0.5
Source of data	ABG model trained with field data
Justification of choice of data	Knowing the impact of the Project on local biodiversity ensures compliance with principles 3, 4, 6 and 7 of the aOCP Program.

Purpose of data	To quantify carbon emissions removals changes caused by the Project.
Stage to be realized	Pre- and post- Project activities

Baseline net GHG removals by sinks

The baseline net GHG removals by sinks shall be calculated as follows:

$$\Delta C_{BSL,t} = \Delta C_{TREE\_BSL,t} + \Delta C_{SHRUB\_BSL,t} + \Delta C_{DW\_BSL,t} + \Delta C_{LI\_BSL,t}$$

Where:

$\Delta C_{BSL.t}$ = Baseline net GHG removals by sinks in year t; t CO2-e

$\Delta C_{TREE\_BSL,t}$= Change in carbon stock in baseline tree biomass within the project boundary in year t, as estimated in the tool “Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities”; t CO2-e

$\Delta C_{SHRUB\_BSL,t}$= Change in carbon stock in baseline shrub biomass within the project boundary, in year t, as estimated in the tool “Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities”; t CO2-e

$\Delta C_{DW\_BSL,t}$ = Change in carbon stock in baseline dead-wood biomass within the project boundary, in year t, as estimated in the tool “Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities”; t CO2-e

$\Delta C_{LI\_BSL,t}$ = Change in carbon stock in baseline litter biomass within the project boundary, in year t, as estimated in the tool “Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities”; t CO2-e

PHASE 1. SETTLEMENT

For the first 5 years of the project, biomass will be retrieved from the bibliography for each vegetal species planted, considering age, and multiplied by the number of individuals of each species. Survival will be monitored yearly and reported mortality will be the basis for replacement and maintenance.

Before and after the establishment of the project , Sentinel-2 and/or drone images will be used to assess the differences in land cover, landscape and spectral response through optical images, band composites and indices (eg. NDVI).

From year 5, when field biometric data will be obtained, AGB will be calculated from species-specific allometric equations.

FIELD DATA

The first five years of the project, tree growth data will be retrieved from the literature, specific for the species and age of the planted trees.

VII. SECTORAL SCOPE APPLICABLE TO AOCP VALIDATOR/VERIFIER

The sectoral scopes eligible under aOCP have been defined in section 3.2 of 'Standard for Development of Methodologies'.

Only a third-party verifier approved under aOCP for the Sectoral scope 16: Afforestation and reforestation can conduct Project validation or Emission Reduction/Removal Verification of aOCP project that applies this methodology.

DOCUMENT HISTORY		
Version	**Date**	**Comments**
V1.0	10/01/2023	• Initial version released for review by the aOCP Steering Committee under the aOCP Version 1.