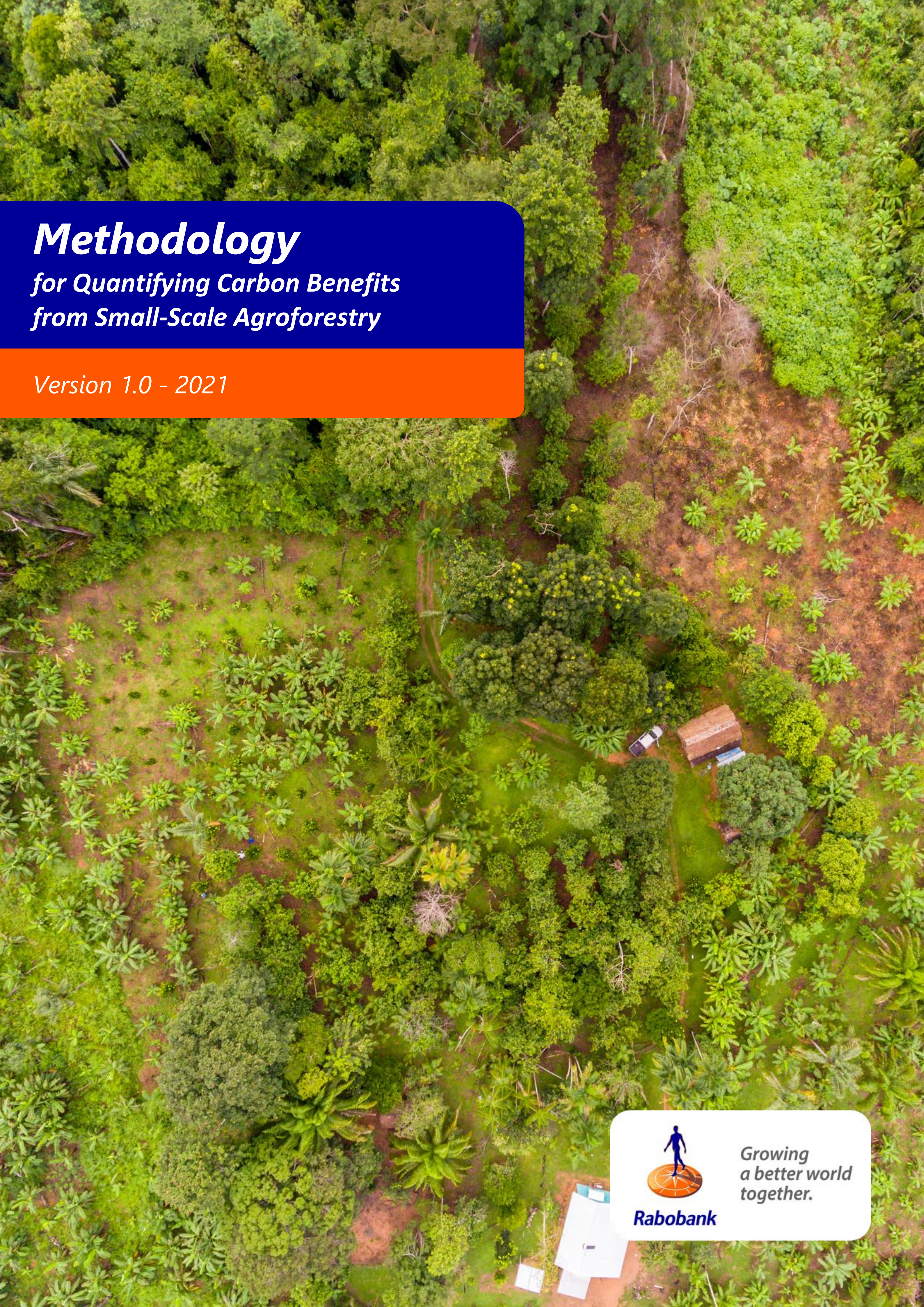

Methodology

for Quantifying Carbon Benefits from Small-Scale Agroforestry

Version 1.0 - 2021

Rabobank

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Title	Methodology for Quantifying Carbon Benefits from Small-Scale Agroforestry
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Sectoral Scope	Agricultural Land Management (ALM) and Afforestation/Reforestation/Revegetation (ARR) through Agroforestry
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Existing methodologies

Methodology	Title	GHG program	Comments
SHAMBA	Smallholder Agriculture Monitoring and Baseline Assessment tool	Plan Vivo	Ex-ante estimation of carbon benefits. Does not include methods for direct measurements
FARM-TRACE	Approved approach for automated forests and carbon assessments	Plan Vivo	Apart from the uncertainty method, the approaches proposed are similar to those in this methodology but are only accessible under license
VM0017	Adoption of Sustainable Agricultural Land Management	VCS	Does not include methods for woody biomass. Refers to CDM Methodologies
VM0042	Methodology for Improved Agricultural Land Management	VCS	Does not include methods for woody biomass. Refers to CDM Methodologies
VT0005	Tool for measuring aboveground live forest biomass using remote sensing	VCS	Includes methods for estimating biomass at one point in time, but not for calculating biomass change and associated uncertainty
AR-ACM0003	Afforestation and reforestation of lands except for wetlands	CDM	Mentions the use of satellite imagery as a possible source of biomass data, but no details are provided. Refers to CDM's AR-TOOL14 methodology
AR-AMS0007	Afforestation and reforestation project activities implemented on lands other than wetlands	CDM	Same as above
AR-TOOL14	Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities	CDM	Determine the carbon baseline

Table 1. Overview of existing methodologies

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1 Sources

This methodology refers to the following CDM Methodologies/Tools:

- AR-ACM0003 A/R Large-scale Consolidated Methodology Afforestation and reforestation of lands except wetlands[1], version 2.0
- AR-TOOL14 *Methodological tool: Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities[2], version 4.2.*

2 Summary of the methodology

This methodology describes the procedures for measuring removals of carbon dioxide from the atmosphere by increasing the carbon stored in tree biomass through the adoption of improved agricultural land management practices based on agroforestry. As such, this methodology can be used to measure carbon benefits achieved (ex-post) and is not intended to estimate carbon benefits expected (ex-ante). The approach quantifies the difference in net emissions of CO_2 from aboveground and belowground biomass between project and baseline scenarios and is applicable to areas of 0.1 to 10 ha that is either cultivated or degraded land at the start of a project intervention.

This methodology is applicable to project interventions that are tailored agroforestry practices on smallholder farms, designed based on scientific and local expertise. To estimate the change in tree biomass attributable to a project intervention between two points in time, the methodology incorporates direct measurement of trees in sample plots, as well as satellite imagery that is interpreted using models derived from sample plot data from the ecoregion within which the project is located. The methodology allows for various approaches to the development of such models and includes requirements to ensure that carbon benefit estimates are robust and conservative. In this way, it takes into account rapid developments in earth observation technology and reduces dependency on standalone methods or tools.

This methodology stems from the “Acorn program” founded by Rabobank; a related “Acorn Framework” has been developed in close collaboration with the Plan Vivo Foundation. Under the Acorn program, carbon benefits will be issued in carbon removal units (CRUs).

[1] *https://cdm.unfccc.int/methodologies/DB/C9QS5G3CS8FW04MYYXDFOQDPXWM4OE*

[2] https://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-14-v4.2.pdf

3 Definitions

Aboveground biomass
The total mass of living matter above the ground is expressed as dry weight.

Agricultural crop
A plant that is grown and harvested for ecosystem benefits, profits or subsistence. This could be fruit, medicinal plants, or nut plants.

Agrisilvicultural
An agroforestry system that mixes crops and trees, such as shade systems (like coffee with citrus trees) or border planting.

Agroforestry
Land-use systems and technologies in which woody perennials (e.g. trees, shrubs, palms or bamboos) and agricultural crops or animals are used deliberately on the same parcel of land in some form of spatial and temporal arrangement. . Agroforestry practices, whether agrisilvicultural, silvopastoral or agrosilvopastoral, should include a subsistence or medicinal component.

Agrosilvopastoral
An agroforestry system that integrates trees, crops and animals, such as home gardens involving animals or woody hedges grown for fodder.

Baseline scenario
The most likely future scenario for land use and land management in a project area in the absence of project intervention(s).

Belowground biomass
The total mass of living matter below the ground is expressed as dry weight.

Buffer Pool
Holds carbon credits that are left unsold as insurance against the risks of non-delivery and reversal of Carbon Benefits. Projects shall set aside carbon benefits to the buffer pool for the duration of the project to cover unforeseen premature loss of carbon stock.

Carbon baseline
Reflects the total carbon stock before the start of a project intervention.

Carbon benefit
An increase in carbon stock relative to the carbon baseline as a result of a project intervention.

Carbon pool
A system that can store and/or accumulate carbon.

Carbon stock
The quantity of carbon in a carbon pool.

Confidence interval
A type of estimate derived from the observed data gives the probability with which the estimated interval will contain the true value of the parameter. It is a combination of the critical values.

Crediting period
The period in which carbon removals from the project intervention will be claimed.

Critical value
A factor is used to compute the margin of error. It is the value that splits the probability of availability or rejection region, which includes or excludes the targeted value in an interval.

Diameter at breast height (DBH)
The measurement of the diameter of a tree at the height of 1.3 meters. For this methodology's purposes, DBH is measured in centimeters.

Ecoregion
A large area of land and/or water, ecologically and geographically characterized by distinct ecosystems, flora, and fauna. Following the "terrestrial scheme" defined by the WWF[3], which splits the world's land surface into 867 ecoregions.

Ground truth measurement
The manual measurement and counting of trees in a specific sample plot of land.

Heavy machinery
Machinery, such as tractors, that does not comply with regenerative agriculture due to high emissions and significant use of non-renewable energy, excluding necessary hand-operated machinery, such as chainsaws, that also require non-renewable energy.

Land property
An entire land property of the farmer (including roads, buildings, timber lots, etc.).

Leakage
An unintended reduction in carbon stocks or increase in t CO_2eq emissions outside a project area, as a result of project activities.

Native species
Plant or animal species that occur naturally within the project area and was not introduced as a result of human activity.

Naturalized species
A non-native species that reproduce consistently and sustains populations over more than one life cycle without direct human intervention.

Non-tree biomass
All non-woody living perennial biomass.

Plot
A discrete area of a smallholder's property within which one or more project intervention(s) is applied, excluding roads, buildings etc. Plots are defined by polygons and can have an extent between 0.1 ha and 10 ha.

Project area
The total area that project interventions are applied to within a project region. A project will include many individual plots of 0.1 to 10 ha in size, which combined make up the total project area of the project.

[3] WWF, 2012

Project intervention
A set of agroforestry activities designed based on scientific and local expertise to restore or improve management of land, increase carbon storage or reduce greenhouse gas emissions, which has a positive impact on local livelihoods and ecosystems.

Sample plot
An area of a maximum of 1 ha within a plot, in which trees are measured to estimate the ground-truth measurement of biomass for models.

Sample subplot
A sample subplot is a 25x25m area located within the sample plot. Established to make ground-truth measurement of biomass easier to execute.

Silvopastoral
An agroforestry system that combines trees and animals, such as cattle grazing in coconut groves.

Soil disturbance
Are referring to activities that result in a decrease in soil organic carbon e.g. ploughing, ripping, scarification, digging of pits and trenches, stump removal etc.

Stratum
By default, this methodology defines a stratum based on a specific ecoregion. Where necessary, further stratification can be done, e.g. based upon variety in pre-project tree biomass or project activities. Sampling only takes place at the stratum (ecoregion) level and is not required on all plots in the project area.

Synthetic fertilizer
Chemically derived fertilizer that is manufactured from minerals, natural gasses and inorganic waste materials.

Tree
A woody perennial biomass that exceeds 2m in height or more than 2.5cm DBH.

4 Applicability conditions

This methodology is intended for the quantification of ex-post carbon benefits from smallholder agroforestry projects in any geographic location. It cannot be used to estimate expected carbon benefits (ex-ante).

This methodology is applicable under the following conditions:

a) The project intervention meets the agroforestry definition (see Section 3), and any trees planted are native or naturalized species.
b) The project area must not have been cleared of native vegetation within 5 years of the start of the project intervention.
c) The project area consists of individual plots that are between 0.1 and 10 ha.
d) All land within the project area is either cropland or degraded land and not on wetlands in the baseline scenario.
e) The project interventions must not include activities that increase the total number, weight or number of grazing days for any livestock type, relative to the baseline scenario.
f) The project intervention must not include the planned harvesting of planted trees during or after the crediting period.
g) Heavy machinery must not be used for site preparation or management.
h) The project intervention must not increase the use of synthetic (nitrogen-containing) fertilizers relative to the baseline scenario.
i) Soil disturbance attributable to the project intervention must not occur on more than 10% of the plot that is under any of the following types of land[4]:
    - Land containing organic soils (see Annex 1)[5];
    - Land which, in the baseline, is subjected to land-use and management practices and receives inputs listed in Annex 2.

Applicability conditions *a* and *b* ensure that project interventions applying the methodology fall within an eligible category for Plan Vivo projects, and meet key environmental safeguards in the Plan Vivo Standard.

Conditions *c,* d and *e* simplify the carbon baseline, and, if met, indicate that carbon removal through litter, deadwood and soil, and emissions from livestock can be conservatively assumed to be zero in the baseline scenario.

Condition *f* enables the application of stock-change approaches for estimating climate benefits, rather than the common stock approach that would be needed if cyclical harvesting took place.

[4] IPCC GPG LULUCF (iges.or.jp)

[5] If land contains high organic soils, projects are expected to contract agreements on limited soil disturbance and clearly stated how soil disturbance is taken into account at the agroforestry design.

Conditions *g*, *h* and *i* ensure carbon emissions from the sources mentioned are likely to be insignificant (collectively less than 5% of the expected climate benefit) or can be conservatively excluded from the estimate of carbon removal.

5 Carbon pools and emission sources

The only carbon pools accounted for in this methodology are aboveground and belowground tree biomass. Justification for the inclusion or exclusion of these and other carbon pools and emission sources is provided in Table 2.

Carbon pool/emission source	Included/excluded	Justification
Aboveground tree biomass	Included	The main carbon pool expected to be impacted by a project intervention
Belowground tree biomass	Included	A major carbon pool expected to be impacted by a project intervention
Aboveground non-tree biomass	Excluded*	Not significantly impacted by a project intervention
Belowground non-tree biomass	Excluded	Not significantly impacted by a project intervention
Litter	Excluded	May increase as a result of a project intervention. Conservatively excluded
Deadwood	Excluded	May increase as a result of a project intervention. Conservatively excluded. The baseline scenario is limited to cropland and degraded land, so there is no potential for removal in this pool
Soil organic carbon	Excluded	Expected to increase as a result of a project intervention. Conservatively excluded. It may be included in future versions of the methodology
Harvested wood products	Excluded	May increase as a result of a project intervention. Conservatively excluded. The baseline scenario is limited to cropland and degraded land, so there is no potential for removal in this pool
Fossil fuel use	Excluded	Not significantly impacted by a project intervention. The use of heavy machinery is excluded
Fertilizers	Excluded	Emissions from this source will be unaffected or reduced by a project intervention, which prohibits any increase in synthetic fertilizer use

*Table 2. Carbon pools and emissions sources * = Note: Non-tree biomass that exceeds 2m in height or more than 2.5cm in DBH may affect the reflectance values of satellite imagery, which will contribute to error in tree biomass estimates, but carbon stocks in non-tree biomass will not be quantified.*

6 Carbon baseline

Following the approach described in AR-TOOL14 v4.2, the carbon stock in aboveground and belowground biomass of pre-project trees can be set at zero in the baseline scenario if:

- The pre-project trees are not harvested, cleared, or removed during the crediting period of the project intervention.
- The pre-project trees do not perish as a result of competing with trees planted in the project or are damaged by project activities, at any time during the crediting period of the project intervention.
- The pre-project trees are not inventoried along with the project trees in the monitoring of carbon stocks but their continued existence, consistent with the baseline scenario, is monitored throughout the crediting period of the project intervention.

For project areas that meet these conditions, baseline removals in all years are assumed to be zero.

If the approach used to monitor tree biomass does not allow for the exclusion of any increase in tree biomass that occurs from the growth of pre-project trees (for example when using remote sensing imagery for monitoring), the conditions that allow for a change in carbon stock to be assumed as zero cannot be met. In these cases, an adjustment for biomass increase in pre-project trees must be applied, as described below.

If the potential change in pre-project tree biomass is less than 5% of the expected increase in tree biomass expected to result from the project intervention, estimated using an appropriate tree or stand growth models, the carbon stock aboveground and belowground biomass of pre-project trees can be set at zero in the baseline scenario. Otherwise, measurements from sample plots must be used to define an appropriate adjustment factor with Equation 1 to Equation *3* and Table 3. The sample plot data used must allow for distinction between pre-project trees and trees planted as part of the intervention. In project regions where pre-project tree biomass varies substantially between plots (e.g. by more than 10%) calculating a separate adjustment factor for each stratum is likely to reduce the number of samples required to obtain an acceptable level of precision. A minimum of 30 randomly selected sample plots must be measured per stratum. Projects may further stratify or use *y-1* to optimize measurement.

$$EETB_{y,s} = \frac{\sum_{i=1}^{n} \left(\frac{(ETB_{y,s} - ETB_{y,s=0})}{(TB_{y,s} - ETB_{y,s=0})} \cdot 100 \right)_i}{n}$$

Equation 1

Where:

$EETB_{y,s}$ = Estimated percentage change in tree biomass in year *y* that is attributed to pre-project trees, for plots in stratum *s*

$ETB_{y,s}$	= Existing tree biomass in sample plot in stratum *s*, *y* years after the start of the project intervention (t CO_2eq)
$ETB_{y,s=0}$	= Existing tree biomass in sample plot in stratum *s* at the start of the project intervention (t CO_2eq)
$TB_{y,s}$	= Tree biomass in sample plot in stratum *s*, *y* years after the start of the project intervention in the sample plot (t CO_2eq).
n	= Number of sample plots in stratum *s*

$$U_{EETB_{y,s}} = \frac{1.645 \cdot \sigma}{\sqrt{n}} \cdot \frac{1}{EETB_{y,s}}$$

Equation 2

Where:

$U_{EETB_{y,s}}$	= Percentage uncertainty of $EETB_{y,s}$ at a 90% confidence level
σ	= Standard deviation of $\left(\frac{(ETB_{y,s}-ETB_{y=0,s})}{(TB_{y,s}-ETB_{y=0,s})} \cdot 100\right)_i$ for all sample plots within stratum *s*
n	= Number of sample plots in stratum *s*

$$AdjU_{EETB_{y,s}} = 0.25 \cdot (U_{EETB_{y,s}} - 0.5)$$

Equation 3

Where:

$AdjU_{EETB_{y,s}}$	= Adjustment for the uncertainty of $EETB_{y,s}$

Estimated change in existing tree biomass in stratum *s* after adjustment for uncertainty ($EETB_{y,s}$ + $AdjU_{EETBy,s}$)	Adjustment factor for baseline removal for plots in stratum *s* ($AdjB_s$)
$(EETB_{y,s} + AdjU_{EETB_{y,s}}) \leq 10\%$	0%
$10\% < (EETB_{y,s} + AdjU_{EETB_{y,s}}) \leq 25\%$	10%
$25\% < (EETB_{y,s} + AdjU_{EETB_{y,s}}) \leq 50\%$	25%
$50\% < (EETB_{y,s} + AdjU_{EETB_{y,s}}) \leq 75\%$	50%
$75\% < (EETB_{y,s} + AdjU_{EETB_{y,s}}) \leq 90\%$	70%
$(EETB_{y,s} + AdjU_{EETB_{y,s}}) > 90\%$	100%

Table 3. Overview of the baseline removal adjustment factor

7 Project carbon removal

This section of the methodology describes how carbon models to measure tree biomass using satellite imagery are developed (see Section 7.1) and applied (see Section 7.2). All carbon models are developed from a combination of sample plot measurements and satellite imagery and are specific to an ecoregion.

Carbon removals from project interventions in each plot, for each year of the crediting period, are calculated as shown in Equation 4.

$$PR_y = \Delta TB_y$$

Equation 4

Where:

PR_y	= Carbon removal for a plot in year *y* (t CO_2eq)
ΔTB_y	= Change in carbon stock in aboveground and belowground tree biomass in year *y* (t CO_2eq) after uncertainty discount

7.1 Model development

7.1.1 Sample plots for ground-truth data collection

Data from sample plots are used to calibrate models for estimating tree biomass from satellite imagery. Sample plots used for model calibration must meet the following requirements:

1. Aboveground and belowground biomass of trees >2m in height or with a DBH of more than 2.5 cm must be measured. For all vegetation of <2m, an inventory list should be collected naming the quantity and species.
2. Sample plots must be within the same ecoregion and with land use similar to that of the plots to which the model will be applied.
3. The location of sample plots must be selected at random from sites that meet the applicability conditions
4. Tree biomass within sample plots can be measured using:
    - The fixed area plot methodology described in Annex 1 of the *Methodological tool: Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities* (AR-TOOL14, v.4.2)
    - The Acorn Standard Operating Procedures for Tree Inventory Plot Establishment and Measurement (Annex 3).
    - Airborne or terrestrial LiDAR survey that meets the minimum requirements set out in Annex 4.

7.1.2 *Remote sensing imagery*

Sources of satellite imagery that can be used include, but are not limited to, those given in Table 4 below. The *minimum* required spatial resolution is 30 m (as currently available with Landsat 8 products). The recommended resolution is 10 m or higher (as currently available with Sentinel-2a and b). Satellite imagery with resolution coarser than 30 m (e.g. MODIS 250m products) cannot be used. For all satellite imagery used, established approaches for pre-processing satellite data must be applied to ensure adequate data quality for estimating aboveground tree biomass, for example, to correct for terrain and cloud effects. The desired temporal resolution for satellite imagery is 1 or more cloud-free observations per 10-day period. For monitoring, at least one cloud-free image every two months must be available so that a minimum of 6 images are available to estimate biomass per year.

Source	Application
Multispectral satellite information	Sentinel-2 is a multispectral imaging mission from the European Space Agency which samples 13 spectral bands with a revisit time of 5 days at the equator. One of the mission objectives is the monitoring and detection of land change[6]. Several parameters are derived from this data to increase the performance of the modelled biomass by validating vegetation presence and vegetation change on the plot. These parameters include the normalized difference vegetation index (NDVI), the fraction of absorbed photosynthetically active radiation (fAPAR), and the leaf area index (LAI). Sentinel-2 offers a higher revisit time and resolution data than NASA's Landsat mission, but Landsat will be used for calibration of existing agroforestry that is older than 2015 (when Sentinel-2 was launched).
LiDAR	This technology uses laser light to create a 3D representation of the Earth's surface (or objects). Any type of LiDAR data (including terrestrial and space-born) can be considered, but due to feasibility and availability, the focus is currently on airborne LiDAR. LiDAR is used only for the validation of ground truth data, and this data is not part of model building. Wang et al. (2019) pointed out that compared to airborne LiDAR, field measurements are more sensitive to stand complexity, crown classes, and species. Overall, field measurements tend to overestimate the height of tall trees, especially tall trees in the codominant crown class. In dense stands, high uncertainties also exist in the field measured heights for small trees in the intermediate and suppressed crown class. However, any validation using LiDAR will not replace ground measurements. Satellite-based LiDAR (GEDI) may be used in model building, although it is tested for its value to future model development.
Future satellite missions	The ESA's Biomass mission should be launched in 2022 and will be the first mission to use P-band synthetic aperture radar (SAR) measurements to determine biomass and carbon amounts stored in forests[7]. This technology and the data it generates will be very useful for estimating biomass and carbon in dense vegetation. Another future mission, NISAR, is also set to launch in 2022. From NASA and the Indian Space Research Organisation (ISRO), this mission comprises L-band and S-band polarimetric synthetic aperture radar to monitor biomass, with a 6-day sampling time. As NISAR will be suitable for low-density vegetation[8], it will complement the Biomass mission.

Table 4. Overview of satellite data sources

[6] *ESA - Sentinel-2*
[7] https://www.esa.int/Applications/Observing_the_Earth/Biomass
[8] *Ecosystems | Science – NASA-ISRO SAR Mission (NISAR)*

The two preferred satellite platforms are Sentinel-2a and b and Landsat 8 and 9. These platforms, if and when they go offline, will be followed by a launch of new platforms. These platforms have an operational lifetime between 12-20 years, as guaranteed by ESA and NASA. If and when they go offline, they will be followed by new and improved satellite missions, which will be compatible and transferable; such launches are planned by both space agencies.

7.1.3 *Model calibration and uncertainty assessment*

Machine learning models for estimating tree biomass from satellite imagery must be calibrated using sample plot data for each ecoregion they are applied to. A minimum of 30 sample plots[9] must be used to calibrate the model for each eco-region, and a further set of at least 20 sample plots that are not used for model calibration must be used to assess model uncertainty. The number of plots used for model calibration and accuracy assessment should be determined based on data availability, variability in the landscape and the desired level of precision.

Model calibration must use six months of composite images, combined using moving averages. At least one pixel must be fully contained within each sample plot used for model calibration. Pixels that have centroid outside the sample plot boundaries are excluded. If multiple pixels fall within the sample plot boundaries, the median value is used for model development.

Model performance must be assessed by calculating model performance (R^2), and model error (MAPE and RMSE) based on a testing set of sample plots that are not used for model calibration[10]. *The mean absolute percentage error (MAPE) is calculated as shown in* Equation *5*

$$MAPE = \frac{1}{n} \cdot \sum_{i=0}^{n} \frac{|\hat{y}_i - y_i|}{y_i}$$

Equation 5

Where:

$MAPE$	= Mean absolute percentage error
y_i	= Measured value of tree biomass within sample plot i (tC)
$\hat{y}_i$	= Value of tree biomass within sample plot i estimated from satellite imagery (tC)
n	= Total number of sample plots

After the model performance has been quantified, the uncertainty of model predictions can be quantified in terms of confidence intervals, which should be estimated in conjunction with the point estimates $\hat{y}_i$ as part of the modelling output.

[9] Corder & Foreman, 2009
[10] R2 and RMSE are regular output of model validation and therefore not mentioned as a separate equation.

7.1.4 *Model validation*

Independent validation of each new model must be performed before it is accepted for use in the production environment. Model validation is a two-step approach.

7.1.4.1 *Independent model validation*

All models used for measuring tree biomass must be validated by an independent legal body that will perform a due diligence and model assessment of the model IP owner (remote sensing partner). The remote sensing partner is not obliged to share details of its IP, but is required to demonstrate the integrity of its processes and data handling.

7.1.4.2 *Internal validation*

A validation dataset should be based on at least 20 randomly selected sample plots that are not used for model calibration or uncertainty assessment. This validation dataset must not be shared with the remote sensing partners that develop the model until model development is complete. The validation dataset must be representative of the sites to which the model will be applied and must conform to the requirements in Section 7.1.1.

After the models are developed, the validation dataset should be shared with the remote sensing partner, which is then asked to apply the model and make biomass estimates.

MAPE, R2 and RMSE are calculated using the validation data set and confidence interval to evaluate which model is suitable and accurate for use. 10% of the plots in the validation set can be removed as outliers, the remaining 90% is used for the calculation.

Model performance must be evaluated at least every 5 years during a project's crediting period. This evaluation is performed using MAPE, R^2 and RMSE as described above. Every new or optimized model, whether improved or with modified accuracy from the current model in place, must be evaluated following the same procedure.

7.1.5 *Accuracy criteria*

The accuracy criteria is based on the withheld validation dataset. The expected accuracy of the model is 70% (with an uncertainty of 30%), calculated on 90% of the validation set. If multiple remote sensing partners are building models for the same ecoregion, the model with the lowest uncertainty is selected for use.

7.2 Model application

7.2.1 *Estimating tree biomass at a point in time*

Aboveground biomass is estimated using a machine learning model. The model is applied to satellite imagery acquired at the time of farmer onboarding (or when required). The model makes an estimate of the total biomass within the plot. The pre-processing of the satellite data must be conducted as stated in Section 7.1.1.

The model can only be applied if the plot is within the relevant ecoregion and applies a project intervention, that the model was calibrated for. If models are unavailable for a particular region, as an alternative, it is also possible to estimate biomass using the ground-truth data approach.

7.2.2 *Estimating change in tree biomass between two points in time*

If a suitable model or measuring tree biomass with satellite imagery is not available, sample plots can be used to estimate tree biomass in a plot directly. In this case, the approach for estimating a change in tree biomass between two points in time, as described in Section 6.1 of the *Methodological tool: Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities* (AR-TOOL 14 v4.2), must be applied. This approach estimates the change in carbon stock in trees as the difference between two successive and independent carbon stock estimates. If tree biomass is estimated using satellite imagery, change in tree biomass must be calculated using Equation 6

$$\Delta TB_{y,s} = \left(AGB_y - AGB_{y-1}\right) \cdot (1 + R) \cdot CF \cdot \frac{44}{12} \cdot (1 - AdjU)$$

Equation 6

Where:

$\Delta TB_{y,s}$	= Change in carbon stock in aboveground and belowground tree biomass in stratum *s*, in year *y* (t CO_2eq) after uncertainty discount
AGB_y	= Aboveground tree biomass per plot in year y (metric tons of dry matter)
AGB_{y-1}	= Aboveground tree biomass per plot in year y-1 (metric tons of dry matter)
R	= Root-shoot ratio to calculate the belowground biomass factor
CF	= Carbon fraction of tree biomass
$\frac{44}{12}$	= Conversion from carbon to carbon dioxide
$AdjU$	= Adjustment factor for uncertainty

If no transparent and verifiable information on local project values is available to justify a particular root-shoot ratio, the root-shoot ratio is determined per ecoregion as determined by IPCC 2006 (see Annex 5) or otherwise, a default value of 0.32[11] will be applied. The carbon faction has a default value of 0.47[12] and is used unless transparent and verifiable information can be provided to justify a different value.

If aboveground biomass in a plot is estimated using satellite imagery, the uncertainty in the temporal change of the aboveground biomass in a plot can be calculated using Equation 7 and Equation 8. Using the value of U_y, the appropriate uncertainty adjustment factor () must be selected from Table 5 below.

$$U_y = \frac{\sqrt{(u_{y-1} \cdot AGB_{y-1})^2 + (u_y \cdot AGB_y)^2}}{|(AGB_y - AGB_{y-1})|}$$

Equation 7

Where:

U_y	= Uncertainty for AGB change estimated in year *y*
AGB_y	= Aboveground biomass per plot in year *y* (metric tons of dry matter)
AGB_{y-1}	= Aboveground biomass per plot in year *y-1* (metric tons of dry matter)
u_y	= Uncertainty for AGB estimated in year *y*
u_{y-1}	= Uncertainty for AGB estimated in year *y-1*

The variable u_y is calculated using Equation 8:

$$u_y = \frac{CI_y}{AGB_y}$$

Equation 8

Where:

u_y	= Uncertainty for AGB point estimate in year y
CI_y	= Half-width of a 90% confidence interval
AGB_y	= Aboveground biomass per plot in year *y* (metric tons of dry matter)

The confidence interval is provided by the remote sensing partner and is determined during model development.

11 *Kim, Kirschbaum & Beedy, 2016*
12 *UNFCCC, 2015*

Uncertainty ($U_{y,s}$)	**Uncertainty adjustment factor $(AdjU)$**
$U_y \leq 50\%$	0%
$50\% < U_y \leq 75\%$	5%
$75\% < U_y \leq 100\%$	15%
$100\% < U_y \leq 150\%$	25%
$150\% < U_y \leq 200\%$	40%
$200\% < U_y \leq 300\%$	60%
$300\% < U_y \leq 400\%$	90%
$U_y > 400\%$	100%

Table 5. Overview of uncertainty adjustment factors based on confidence interval.

8 Leakage

The likelihood of activity shifting leakage (displacement of farmer activity leading to an increase in emissions outside the project area) must be assessed using Equation 9 to determine an appropriate leakage adjustment. To come up with a conservative deduction, the following three parameters are evaluated: i) which activities may be displaced? ii) where would the activity be displaced to? and iii) what amount of emissions would be associated with the displacement? Market leakage from changes in production by smallholders is not expected to be significant and is assumed to be zero.

$$AdjL = P \cdot A \cdot LF \cdot 100$$

Equation 9

Where:

$AdjL$	= Adjustment factor for leakage (percentage)
P	= The estimated reduction in productivity that will result from the project intervention, as a percentage of the productivity expected in the baseline scenario. If no change or an increase in productivity is expected, the score should be 0%
A	= The proportion of the project area used to produce the most important product, or carry out the activity, that contributes to productivity in the baseline scenario, e.g. if half the plot is used to grow a specific crop the score should be 0.5
LF	= Leakage factor for the type of land that production will be likely to shift to as a result of the project intervention: cropland or degraded land is 0 and forest land or wetland or organic soils[13] is 1

[13] *IPCC GPG LULUCF (iges.or.jp)*

9 Quantification of carbon benefits

Carbon removal is calculated for each year of the crediting period using Equation 10

$$CB_y = PR_y \cdot \frac{1}{1+BP} \cdot \left(1 - AdjB_s\right) \cdot (1 - AdjL)$$

Equation 10

Where:

CB_y	= Carbon benefit for a plot in year *y* (t CO_2eq)
PR_y	= Carbon removal for a plot in year *y* (t CO_2eq)
BP	= Buffer pool percentage
$AdjB_s$	= Adjustment factor for baseline removal for plots in stratum *s*
$AdjL$	= Adjustment factor for leakage

Only a positive change compared to the previous highest AGB calculation during the project intervention is considered. No negative change at plot level is accounted for (see Figure 1 below).

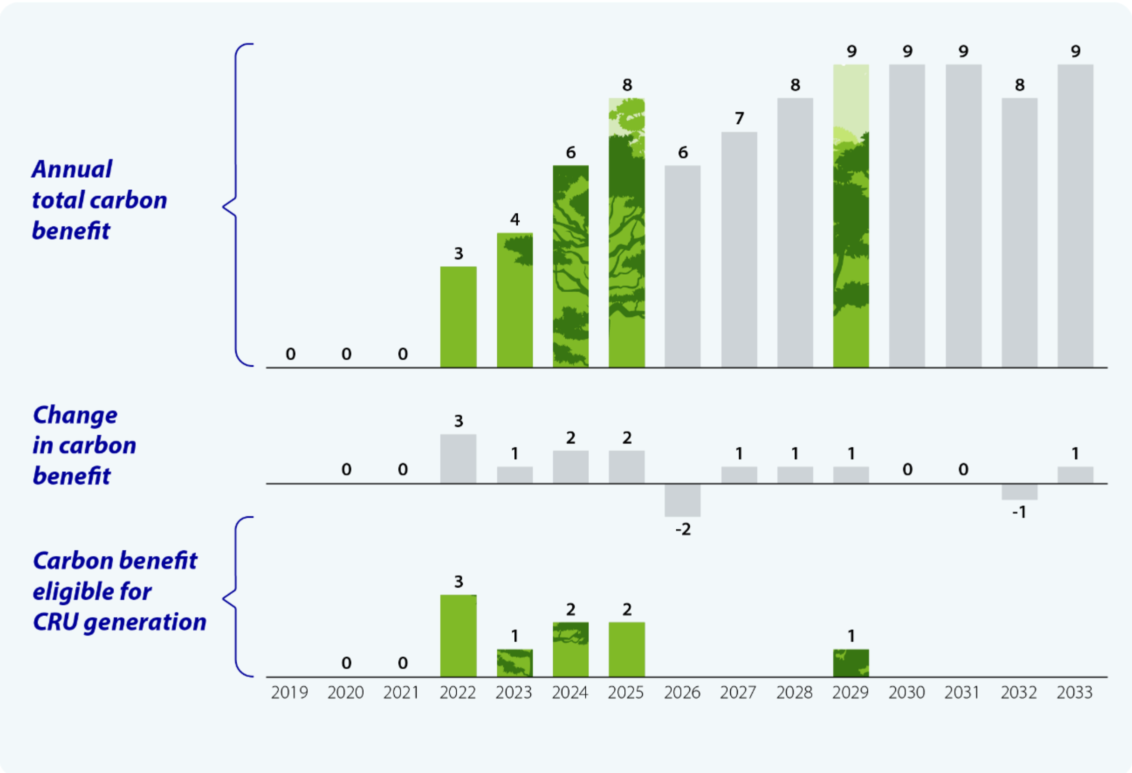

Figure 1. Carbon benefit calculation

10 Data and parameters

10.1 Data and parameters available at validation

Data / parameter:	$ETB_{y=0,s}$
Data unit:	t CO_2eq
Description:	Existing tree biomass in sample plot in stratum *s* at the start of the project intervention
Equations	*Equation 1*
Source of data:	Survey of sample plots defined by type of project intervention, time since establishment of the intervention, and pre-project tree biomass or analysis of satellite imagery.
Description of measurement methods and procedures to be applied:	The Acorn Standard Operating Procedures for Tree Inventory Plot Establishment and Measurement (Annex 3); or fixed area plot methodology that is described in Annex 1 of the Methodological tool: Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities (AR-TOOL14 v.4.2); or another established SOP that follows international best-practice in plot measurements. Or see Section 7.2.
Frequency of monitoring/recording:	Once at the start of the project intervention in the Sample Plot
Purpose of data:	Calculation of the baseline removal adjustment factor to account for change in pre-project tree biomass in the baseline scenario
Calculation method:	Sum of above and below ground biomass of all pre-project trees within the Sample Plot
Comments:	Only required for plots where change in biomass of trees cannot be estimated as zero in the baseline scenario

Data / parameter:	R
Data unit:	No unit
Description:	Root-shoot ratio for belowground biomass factor
Equations	*Equation 6*
Source of data:	Determined by local data project value or ecological zones (*Ravindranath & Ostwald, 2008*) or otherwise, a default value of R=0.32 (*Kim, Kirschbaum & Beedy, 2016)* unless transparent and verifiable information can be provided to justify a different value
Description of measurement methods and procedures to be applied:	N/A

Frequency of monitoring/recording:	Once at start of project. Can be updated at time of verification
Purpose of data:	Estimation of belowground biomass contribution
Calculation method:	N/A
Comments:	N/A

Data / parameter:	CF
Data unit:	No unit
Description:	Carbon fraction of tree biomass
Equations	*Equation 6Equation 6*
Source of data:	*UNFCCC, 2015*
Description of measurement methods and procedures to be applied:	N/A
Frequency of monitoring/recording:	Once at start of project. Can be updated at time of verification
Purpose of data:	Estimation of carbon stocks in tree biomass
Calculation method:	N/A
Comments:	N/A

Data / parameter:	P
Data unit:	No unit
Description:	The estimated reduction in productivity will result from the project intervention, as a percentage of the productivity expected in the baseline scenario. If no change or an increase in productivity is expected, the score should be 0%
Equations	*Equation 9*Equation 9
Source of data:	Analysis of the business case and baseline scenario
Description of measurement methods and procedures to be applied:	N/A
Frequency of monitoring/recording:	Once at the start of a project. Can be updated at the time of validation
Purpose of data:	Calculation of the leakage adjustment factor to account for a potential increase of emissions outside the project area
Calculation method:	Sum of activity leakage parameters
Comments:	N/A
Data / parameter:	A

Data unit:	No unit
Description:	The proportion of the project area used to produce the most important product, or carry out the activity, that contributes to productivity in the baseline scenario, e.g. if half the plot is used to grow a specific crop the score should be 0.5
Equations	*Equation 9*
Source of data:	Analysis of the business case and baseline scenario
Description of measurement methods and procedures to be applied:	N/A
Frequency of monitoring/recording:	Once at the start of a project. Can be updated at the time of validation
Purpose of data:	Calculation of the leakage adjustment factor to account for a potential increase of emissions outside the project area
Calculation method:	Sum of project area proportions
Comments:	N/A

Data / parameter:	LF
Data unit:	No unit
Description:	Leakage factor for the type of land that production will be likely to shift to as a result of the project intervention: cropland or degraded land is 0 and forest land or wetland or organic soils is 1
Equations	*Equation 9*
Source of data:	Analysis of the baseline scenario
Description of measurement methods and procedures to be applied:	N/A
Frequency of monitoring/recording:	Once at the start of a project. Can be updated at the time of validation
Purpose of data:	Calculation of the leakage adjustment factor to account for a potential increase of emissions outside the project area
Calculation method:	N/A
Comments:	N/A

10.2 Data and parameters monitored

Data / parameter:	$ETB_{y,s}$
Data unit:	t CO_2eq
Description:	Existing tree biomass in sample plot in stratum *s*, *y* years after the start of the project intervention
Equations	*Equation 1*
Source of data:	Survey of sample plots defined by the type of project intervention, time since the establishment of the intervention, and pre-project tree biomass
Description of measurement methods and procedures to be applied:	Similar to measurement of $ETB_{y=0,s}$ but additional inventory procedures must distinguish between pre-project trees and those established since the start of the project intervention within the sample plot
Frequency of monitoring/recording:	Periodically throughout the crediting period
Purpose of data:	Calculation of the baseline removal adjustment factor to account for a change in pre-project tree biomass in the baseline scenario
Calculation method:	Sum of aboveground and below ground biomass of all pre-project trees within the sample plot
Comments:	Only required for plots where a change in biomass of trees cannot be estimated as zero in the baseline scenario

Data / parameter:	$TB_{y,s}$
Data unit:	t CO_2eq
Description:	Tree biomass in sample plot in stratum *s*, *y* years after the start of the project intervention in the sample plot
Equations	*Equation 1*
Source of data:	Analysis of satellite imagery or survey of sample plots
Description of measurement methods and procedures to be applied:	As described in Section 7; or the Acorn Standard Operating Procedures for Tree Inventory Plot Establishment and Measurement (Annex 3); or as described in Annex 1 of the *Methodological tool: Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities* (AR-TOOL14 v.4.2); or another established SOP that follows international best practice in plot measurement
Frequency of monitoring/recording:	Periodically throughout the crediting period
Purpose of data:	Calculation of the baseline removal adjustment factor to account for a change in pre-project tree biomass in the baseline scenario
Calculation method:	Sum of above and below ground biomass of all trees within the sample plot

Comments:	Only required for plots where a change in biomass of trees cannot be estimated as zero in the baseline scenario

Data / parameter:	y_i
Data unit:	tC
Description:	The measured value of tree biomass within sample plot i
Equations	Equation *5*
Source of data:	Sample plot
Description of measurement methods and procedures to be applied:	Fixed area plot methodology as described in Annex 1 of the *Methodological tool: Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities (AR-TOOL14 v.4.2);* the Acorn Standard Operating Procedures for Tree Inventory Plot Establishment and Measurement (Annex 3); or another established SOP that follows international best practice in plot measurement
Frequency of monitoring/recording:	Before each verification
Purpose of data:	Development and performance assessment of model for estimating tree biomass from satellite imagery
Calculation method:	As described in SOP adopted
Comments:	N/A

Data / parameter:	$\hat{y}_i$
Data unit:	tC
Description:	Value of tree biomass within sample plot i estimated from satellite imagery
Equations	Equation *5*
Source of data:	Analysis of satellite imagery
Description of measurement methods and procedures to be applied:	Section 7
Frequency of monitoring/recording:	Before each verification
Purpose of data:	Development and performance assessment of model for estimating tree biomass from satellite imagery
Calculation method:	Section 7
Comments:	N/A

Data / parameter:	AGB_y; AGB_{y-1}
Data unit:	metric tons of dry matter
Description:	Aboveground tree biomass per ha in year y; aboveground tree biomass per ha in year y-1
Equations	Equation *6*
Source of data:	Survey of sample plots or analysis of satellite imagery
Description of measurement methods and procedures to be applied:	Section 7.2
Frequency of monitoring/recording:	Annually, or at least every 3 years
Purpose of data:	Estimation of project removals
Calculation method:	Section 7.2
Comments:	N/A

Data / parameter:	u_y; u_{y-1}
Data unit:	metric tons of dry matter
Description:	Uncertainty for AGB point estimate in year *y*; uncertainty AGB point estimate in year *y-1*
Equations	Equation *7*
Source of data:	Analysis of satellite imagery
Description of measurement methods and procedures to be applied:	Section 7.2
Frequency of monitoring/recording:	Before each verification.
Purpose of data:	Estimating uncertainty of change in aboveground biomass
Calculation method:	Section 7.2
Comments:	N/A

Data / parameter:	CI_y
Data unit:	metric tons of dry matter
Description:	Half width of a 90% confidence interval
Equations	Equation *8*
Source of data:	Analysis of satellite imagery
Description of measurement	Section 7.2

methods and procedures to be applied:	
Frequency of monitoring/recording:	Before each verification
Purpose of data:	Estimating uncertainty of change in aboveground biomass
Calculation method:	Section 7.2
Comments:	N/A

Data / parameter:	BP
Data unit:	No unit
Description:	Buffer pool percentage
Equations	*Equation 10*
Source of data:	Coverage ratio and Acorn Framework
Description of measurement methods and procedures to be applied:	N/A
Frequency of monitoring/recording:	Once at the start of a project. Can be updated at the time of verification
Purpose of data:	Carbon removal buffer for reversal events
Calculation method:	N/A
Comments:	N/A

*This parameter may be used but is only necessary for projects under the Acorn program	
Data / parameter:	Biodiversity
Data unit:	No unit
Description:	A count of crops species and animal breeds shall be used to calculate a Gini-Simpson index of diversity for both crops and animals
Equations	N/A
Source of data:	A survey amongst a group of sampled farmers should be conducted on a frequent basis to track changes in the biodiversity situation of a project.
Description of measurement methods and procedures to be applied:	Species and animals are counted and the numbers are reported in the survey
Frequency of monitoring/recording:	Sample based once every 3 years

Purpose of data:	Determine the Gini-Simpson index to indicate the appropriate biodiversity category and allow for comparison amongst projects and operational years
Calculation method:	Multiple species count with related livestock equivalent[14]. Monitoring templates can be requested from Acorn
Comments:	Please note that this parameter is only necessary for project applying under the Acorn program. More information about the monitoring requirements can be found in the Acorn Framework Section 5.4 Project baseline available via the Acorn website

*This parameter may be used but is only necessary for projects under the Acorn program	
Data / parameter:	Soil disturbance
Data unit:	Ha
Description:	If projects operate on considered high organic soils, the land should be taken care of caution (i.e. limited digging)
Equations	N/A
Source of data:	The SoilGrid[15] of ISRIC
Description of measurement methods and procedures to be applied:	Sample-based check if extensive soil disturbance activities have taken place e.g. ploughing, ripping, scarification, digging of pits and trenches, stump removal
Frequency of monitoring/recording:	Sampled validation and verification checks. Very unlikely, but only if projects operate on high organic soils. Agroforestry system growth models allow to validate and verify the appropriate implementation of the agroforestry system respecting the soil disturbance limitations
Purpose of data:	Avoid projects to transition to agroforestry on land that already contains high carbon stock and this transition causes emission loss rather than additional storage
Calculation method:	N/A
Comments:	Please note that this parameter is only necessary for a project applying under the Acorn program. More information about the monitoring requirements can be found in the Acorn Framework Section 5.4 Project baseline available via the Acorn website

Table 6. Overview of parameters

[14] *Glossary: Livestock unit (LSU) - Statistics Explained (europa.eu)*
[15] *ISRIC — World Soil Information*

Annex 1 Organic soils

As per IPCC (2006), soils are characterized as organic if the following characteristics are met 1 and 2, or 1 and 3 (FAO, 1998).

1. Thickness of 10 cm or more. A horizon less than 20 cm thick must have 12 percent or more organic carbon when mixed to a depth of 20 cm;
2. If the soil is never saturated with water for more than a few days, and contains more than 20 percent (by weight) organic carbon (about 35 percent organic matter);
3. If the soil is subject to water saturation episodes and has either:
   I.) At least 12 percent (by weight) organic carbon (about 20 percent organic matter) if it has no clay; or
   II.) At least 18 percent (by weight) organic carbon (about 30 percent organic matter) if it has 60 percent or more clay; or
   III.) An intermediate, proportional amount of organic carbon for intermediate amounts of clay.

Annex 2 Soil disturbance

Region	Land use	Management	Inputs
Boreal	Long-term cultivated cropland	Full tillage	High with manure
		Reduced tillage	High with manure
		No-till	High without manure
			High with manure
	Short-term or set aside cropland	Full tillage	High with manure
		Reduced tillage	High with manure
		No-till	High without manure
			High with manure
Temperate, cold, dry	Long-term cultivated cropland	Full tillage	High with manure
		Reduced tillage	High with manure
		No-till	High with manure
	Short-term or set aside cropland	Full tillage	High with manure
		Reduced tillage	High with manure
		No-till	Medium
			High without manure

Region	Land use	Management	Inputs
Temperate, cold, moist	Long-term cultivated cropland	Reduced tillage	High with manure
		No-till	High with manure
	Short-term or set aside cropland	Full tillage	High with manure
		Reduced tillage	High with manure
		No-till	High without manure
			High with manure
Temperate, warm, dry	Long-term cultivated cropland	Full tillage	High with manure
		Reduced tillage	High with manure
		No-till	High with manure
	Short-term or set aside cropland	Full tillage	High with manure
		Reduced tillage	High with manure
		No-till	Medium
			High without manure
Temperate, warm, moist	Long-term cultivated cropland	Reduced tillage	High with manure
		No-till	High with manure
	Short-term or set aside cropland	Full tillage	High with manure
		Reduced tillage	High with manure
		No-till	High without manure
			High with manure
Tropical, dry	Short-term or set aside cropland	Full tillage	High with manure
		Reduced tillage	Medium
			High without manure
			High with manure
		No-till	All
Tropical, moist	Short-term or set aside cropland	Full tillage	High with manure
		Reduced tillage	High without manure

Region	Land use	Management	Inputs
			High with manure
		No-till	High without manure
			High with manure
Tropical, montane	Long-term cultivated cropland	No-till	High with manure
	Short-term or set aside cropland	Full tillage	High with manure
		Reduced tillage	High without manure
			High with manure
		No-till	Medium
			High without manure
			High with manure
Tropical, wet	Short-term or set aside cropland	Full tillage	High with manure
		Reduced tillage	High without manure
			High with manure
		No-till	High without manure
			High with manure

Temperature / Moisture Regime	Management	Inputs
Boreal	Improved	All
	Non-degraded	All
	Moderately degraded	High
Temperate, cold, dry	Improved	All
	Non-degraded	All
	Moderately degraded	High
Temperate, cold, moist	Improved	All
	Non-degraded	All
	Moderately degraded	High
Temperate, warm, dry	Improved	All
	Non-degraded	All
	Moderately degraded	High
Temperate, warm, moist	Improved	All
	Non-degraded	All
	Moderately degraded	High
Tropical, dry	Improved	All
	Non-degraded	All
Tropical, moist	Improved	All
	Non-degraded	All
	Moderately degraded	High
Tropical, montane	Improved	All
	Non-degraded	All
	Moderately degraded	High
Tropical, wet	Improved	All
	Non-degraded	High
	Moderately degraded	High

Table 7. List of cropland and grassland in which soil disturbance is restricted based upon AR-ACM0003 v.2.0

Annex 3 SOP for tree inventory plot establishment and measurement

The plot, sample plot and subplot overview

Figure 2. Graphical representation of a farmer's land property, incl. relevant definitions

1. Land-property: entire land-property of the farmer (excluding roads, houses, timber lots, etc.).
2. Plot (GPS Polygon): A plan figure with straight sides corresponding to the entire land property.
3. Sample Plot: 1 ha plot within the total land property of the farmer.
4. Subplot: a 25x25m subplot that is located within the main plot.
5. 1 hectare: 100x100m of land (during field collection should be located within the land property).

Instructions for obtaining ground-truth measurements for aboveground biomass

1 Download an offline map for identifying coordinates

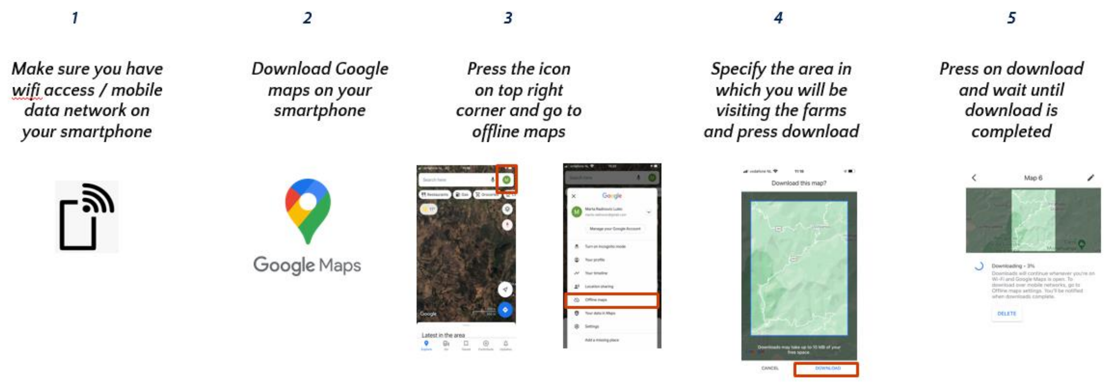

Figure 3. Step-by-step approach for offline map

To determine the plot coordinates at the location use your GPS device (ideally a professional device such as Garmin eTrex 10, but a smartphone will suffice).

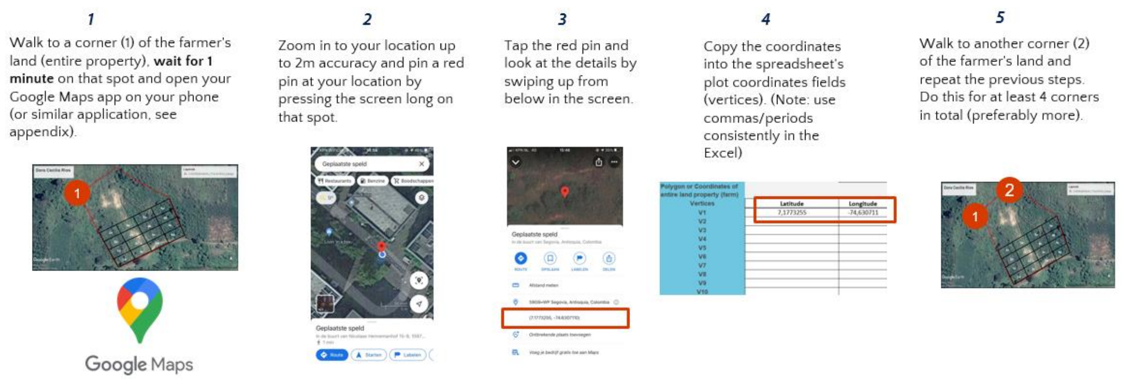

Figure 4. Step-by-step approach to determine coordinates

2 Define sample plot

The first step is to determine, a sample plot on the entire land property of the farmer. An easy and accurate way to do this online is to use the Google Earth software to define the sample plot and coordinates of the corner points. By using the "add polygon function", a polygon can be created to fit the chosen area. The option "measurements" shows the exact area, which should be at least 1 ha[16].

Polygons may also be created with smartphone-based GPS and apps, or alternatively using handheld GPS devices. After establishing the polygon of the entire land property, corners of a sample plot (a 1 ha area on the entire land property) can be pinpointed to provide its GPS coordinates of the sample plot. Placing coloured poles and/or flags at these corner points ensures that trees are measured within the right area.

3 Define subplots within the sample plot

To simplify the measuring of the trees on the ground a second step, the sample plot is divided into subplots, which are preferably square-shaped plots of 25x25 meters. Each subplot is numbered and added to a simple sketch that lays out the entire sample plot, as shown in Figure 5 below. Again, to ensure the measurement is done adequately, subplots are demarcated using poles and/or flags at the corner points.

[16] Note: Smaller plots are feasible but not desirable. If a sample plot is smaller than 1 ha, the size of the whole sample plot is measured, with as many sub-plots as possible.

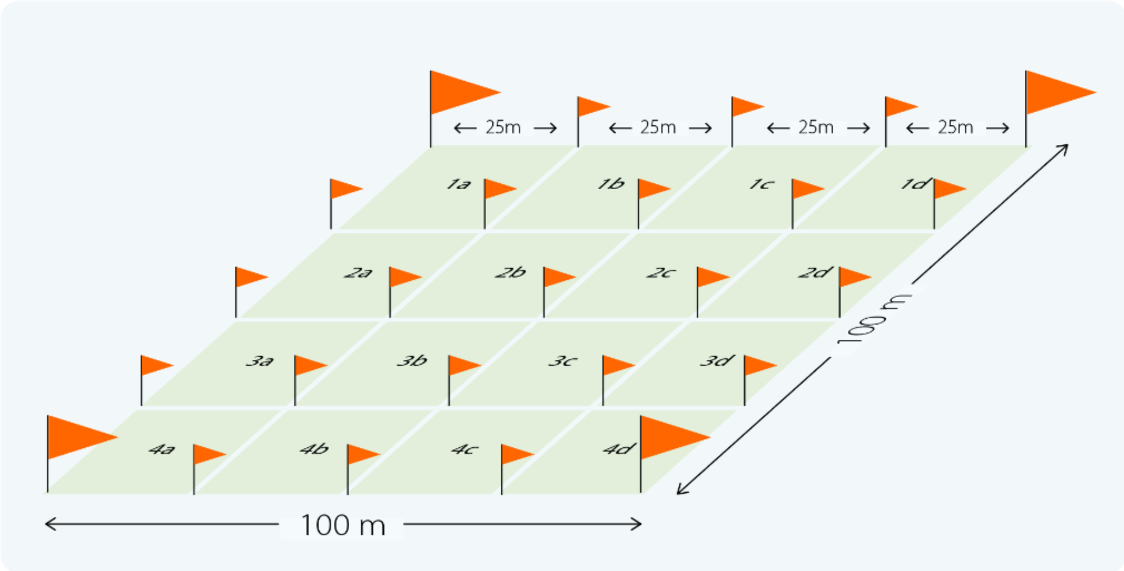

Figure 5. Example of a sample plot

4 Measure trees per subplot

After the subplots are demarcated, the trees are measured in a structured way from west to east and from north to south, working from one side of the subplot to the other. All trees with a DBH of more than 2.5 cm or a height of 2 m should be measured. Once all data on a tree has been gathered, the tree can be marked with chalk which prevents double counting of trees. If a tree is located on the plot border, determine whether the majority of the stem is located in or outside the plot– if within, the tree will be counted and if outside, the tree will not be counted.

For each tree, the scientific species name or common name must be noted. If a species cannot be identified in the field, photographs should be taken of the whole tree, the top and bottom sides of the leaves including the petiole, the trunk of the tree, and, if present, the fruits or flowers. The picture code or exact time when the photographs were taken are recorded to link the tree data to the pictures.

To measure DBH, the circumference (the orange line in Figure 6) of each tree is measured horizontally at a height of 1.3 m using a measuring or diameter tape. The corresponding diameter (blue line in Figure 6) is reported. Figure 7 below illustrates several tree shapes and is followed by a description of how to measure DBH in each of these cases.

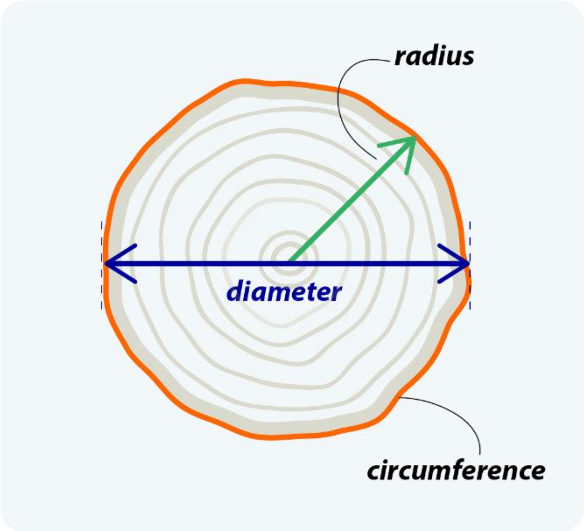

Figure 6. Diameter, circumference, and radius

At least the following information should be reported
Per sample plot

- GPS coordinates (preferably in DD format)
- Name of collector
- Name of farm/farmer
- Date, location

Per subplot

- GPS coordinates (preferably in DD format)
- Per type of tree
    - Height
    - Diameter
    - Scientific name
    - Year planted

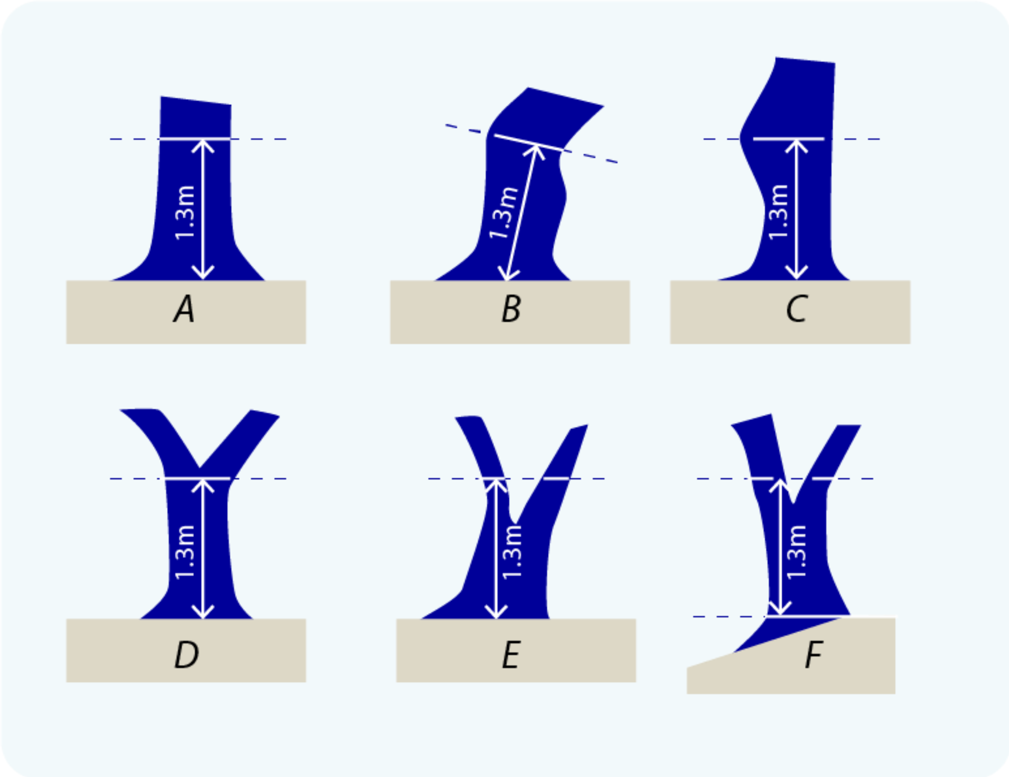

Figure 7. Where to measure DBH on different shapes of trees

a) Normal tree: Wrap the measuring tape horizontally around the tree.
b) Bent tree: Wrap the measuring tape around the tree in the shortest way, which is often not horizontal.
c) Tree with an irregular diameter at 1.3 m: Measure DBH below and above the irregularity and report the average value.
d) Tree forked above 1.3 m: Measure as a normal tree.
e) Tree forked below 1.3 m: Measure stems as separate trees.
f) Tree located on a hill: Measure at 1.3 m height from the highest point of the soil.

Additionally, for each tree, the tree height must be noted. To measure tree height, the use of a laser tool such as a Nikon Forestry Pro Rangefinder is preferred, as it gives the most accurate tree height measurements. If one is not available, estimates of tree height using a ruler can be made according to the method illustrated in Figure 8.

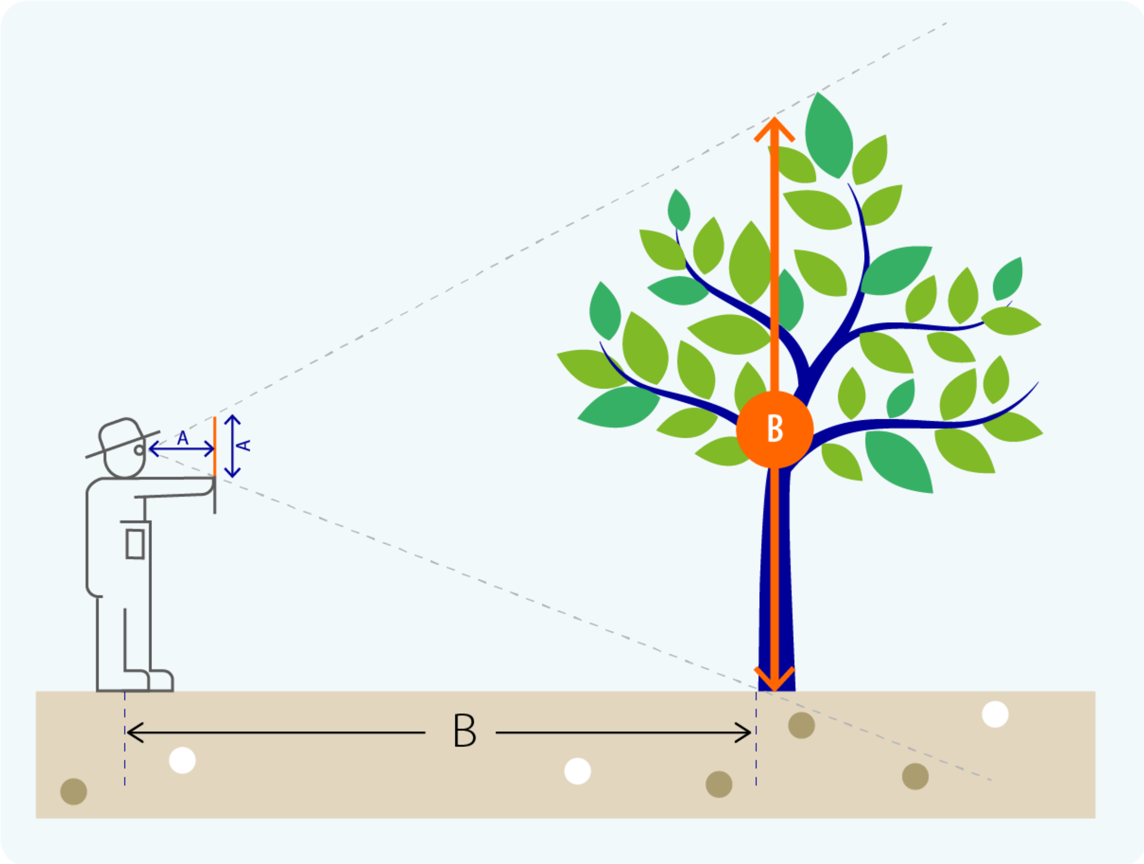

Figure 8. How to measure the height of a tree without a laser measuring tool

1. Measure the horizontal distance from your eye to the hand of your outstretched arm (a).
2. Hold the ruler vertically in front of you. The distance from the top of the ruler to where you hold it must be the same length as the distance from your eye to your hand (a).
3. Walk towards or away from the tree until the tree is visually the same length as the length between the top of the ruler to your hand (a).
4. Mark the location where you are standing and measure the distance from there to the trunk of the tree (b). This distance is roughly the height of the tree (b).

5 Translate tree measurement into AGB

The last step to convert collected data to a biomass value is to apply the aboveground biomass model as developed based on Equation 4 of Chave et.al. (2014). This model takes DBH, tree height, and wood density as variables to estimate the actual biomass.

Annex 4 LiDAR survey requirements

Attribute	Ideal	Minimum
Average point density	20-24 point/m2	20 points/m2
LiDAR data platform	Helicopter/aircraft	Helicopter/aircraft
Lateral overlap	60%	30% +/- 3%
Product accuracy	25 cm	10 – 30 cm
Ground control points	Needed, 3-5 ground control points	Yes, 3 ground control points
Processed data products	Georeferenced point cloud, DSM, DTM, orthophoto, contour lines	Georeferenced point cloud, DSM, DTM, orthophoto

Table 8. LiDAR requirements

Annex 5 Root-shoot ratio

TABLE 4.4 RATIO OF BELOW-GROUND BIOMASS TO ABOVE-GROUND BIOMASS (R)				
Domain	**Ecological zone**	**Above-ground biomass**	**R [tonne root d.m. (tonne shoot d.m.)$^{-1}$]**	**References**
Tropical	Tropical rainforest		0.37	Fittkau and Klinge, 1973
	Tropical moist deciduous forest	above-ground biomass <125 tonnes ha^{-1}	0.20 (0.09 - 0.25)	Mokany *et al.*, 2006
		above-ground biomass >125 tonnes ha^{-1}	0.24 (0.22 - 0.33)	Mokany *et al.*, 2006
	Tropical dry forest	above-ground biomass <20 tonnes ha^{-1}	0.56 (0.28 - 0.68)	Mokany *et al.*, 2006
		above-ground biomass >20 tonnes ha^{-1}	0.28 (0.27 - 0.28)	Mokany *et al.*, 2006
	Tropical shrubland		0.40	Poupon, 1980
	Tropical mountain systems		0.27 (0.27 - 0.28)	Singh *et al.*, 1994
Subtropical	Subtropical humid forest	above-ground biomass <125 tonnes ha^{-1}	0.20 (0.09 - 0.25)	Mokany *et al.*, 2006
		above-ground biomass >125 tonnes ha^{-1}	0.24 (0.22 - 0.33)	Mokany *et al.*, 2006
	Subtropical dry forest	above-ground biomass <20 tonnes ha^{-1}	0.56 (0.28 - 0.68)	Mokany *et al.*, 2006
		above-ground biomass >20 tonnes ha^{-1}	0.28 (0.27 - 0.28)	Mokany *et al.*, 2006
	Subtropical steppe		0.32 (0.26 - 0.71)	Mokany *et al.*, 2006
	Subtropical mountain systems		no estimate available	
Temperate	Temperate oceanic forest, Temperate continental forest, Temperate mountain systems	conifers above-ground biomass < 50 tonnes ha^{-1}	0.40 (0.21 - 1.06)	Mokany *et al.*, 2006
		conifers above-ground biomass 50-150 tonnes ha^{-1}	0.29 (0.24 - 0.50)	Mokany *et al.*, 2006
		conifers above-ground biomass > 150 tonnes ha^{-1}	0.20 (0.12 - 0.49)	Mokany *et al.*, 2006
		Quercus spp. above-ground biomass >70 tonnes ha^{-1}	0.30 (0.20 - 1.16)	Mokany *et al.*, 2006
		Eucalyptus spp. above-ground biomass < 50 tonnes ha^{-1}	0.44 (0.29 - 0.81)	Mokany *et al.*, 2006
		Eucalyptus spp. above-ground biomass 50-150 tonnes ha^{-1}	0.28 (0.15 - 0.81)	Mokany *et al.*, 2006
		Eucalyptus spp. above-ground biomass > 150 tonnes ha^{-1}	0.20 (0.10 - 0.33)	Mokany *et al.*, 2006
		other broadleaf above-ground biomass < 75 tonnes ha^{-1}	0.46 (0.12 - 0.93)	Mokany *et al.*, 2006
		other broadleaf above-ground biomass 75-150 tonnes ha^{-1}	0.23 (0.13 - 0.37)	Mokany *et al.*, 2006
		other broadleaf above-ground biomass >150 tonnes ha^{-1}	0.24 (0.17 - 0.44)	Mokany *et al.*, 2006
Boreal	Boreal coniferous forest, Boreal tundra woodland, Boreal mountain systems	above-ground biomass <75 tonnes ha^{-1}	0.39 (0.23 - 0.96)	Li *et al.*, 2003; Mokany *et al.*, 2006
		above-ground biomass >75 tonnes ha^{-1}	0.24 (0.15 - 0.37)	Li *et al.*, 2003; Mokany *et al.*, 2006

Table 9. Ratio (R) of belowground biomass to aboveground biomass (metric tons of root dry matter; metric tons of shoot dry matter) From IPCC 2006, Guidelines for National Greenhouse Gas Interventions – Chapter 4 Forest Land, *Table 4.4, pp 4.49.*

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