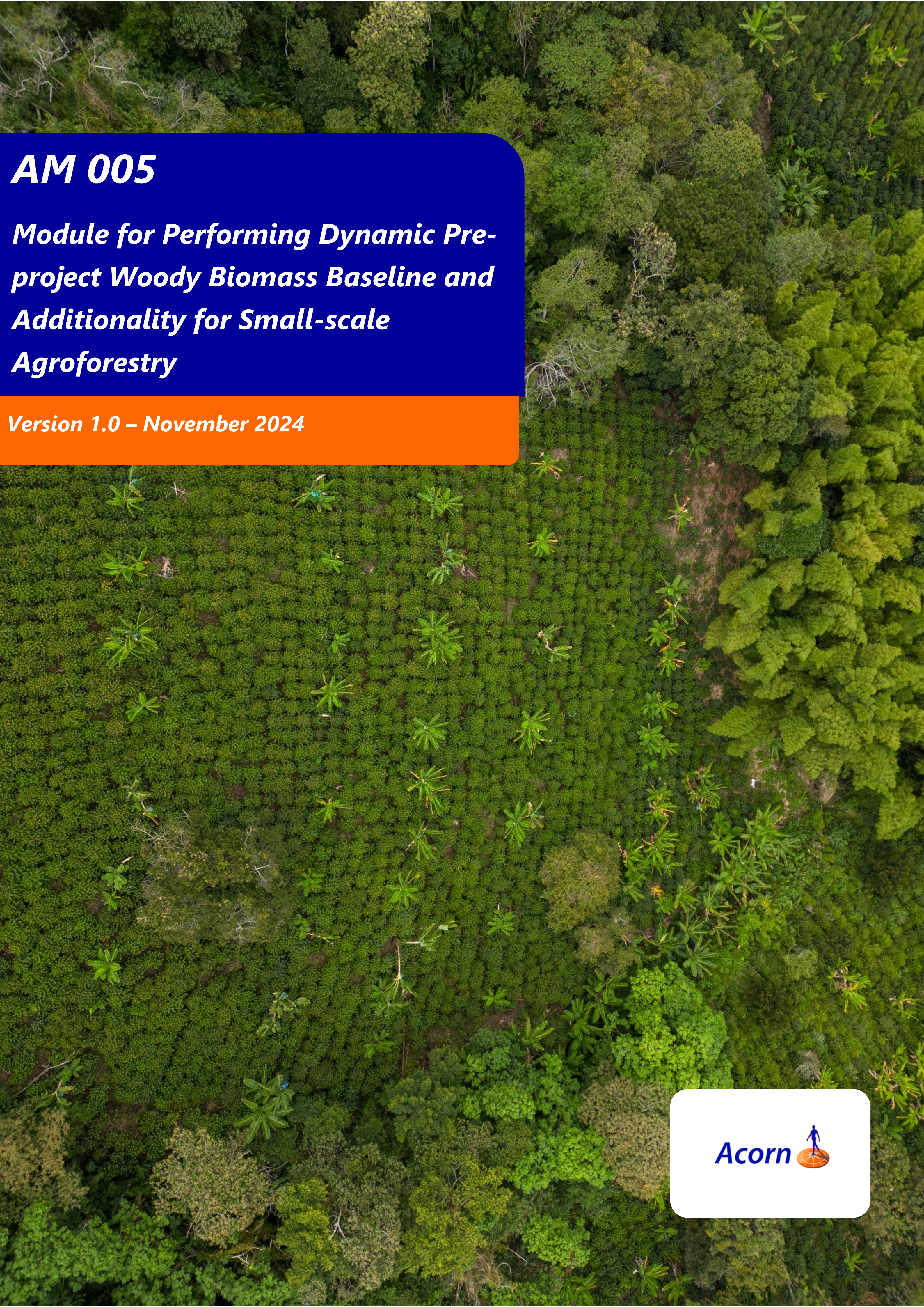

AM 005

Module for Performing Dynamic Pre-project Woody Biomass Baseline and Additionality for Small-scale Agroforestry

Version 1.0 – November 2024

Acorn

Contents

1 Summary

This module provides a method for performing dynamic baseline of woody *biomass* present within the *project area*, prior to the start of the *Acorn Project Period*. Furthermore, the module provides an approach to demonstrating Acorn's additionality by simulating scenarios via sensitivity testing.

Using a sigmoid-based growth curve, the module provides an approach for determining the expected *biomass* growth of the pre-existing and newly planted trees in the *Acorn project*. The output of the model is used within the Acorn Methodology **(AM-001 v2.0)** to estimate whether an adjustment factor needs to be applied.

The input tree-related parameters are derived from a subset of *ground truth plots*, used for field measurements, also referred to as *control plots*. These parameters include but are not limited to trees with a height above 1.3 meters, species names, year of planting, and derived *biomass* per hectare. The sigmoid-based growth curve is applied to each individual species. If the set of parameters is not complete, a generic growth curve is used based on the overall trees in the *Acorn project*. For species in the *Agroforestry Design* without enough data, a growth curve is constructed based on theoretical information and/or ground measurements from comparable projects.

For each *control plot*, the individual *biomass* is estimated for each year of the project based on the species growth curves (or general growth curve if no specific curve could be constructed). The *control plots* are revisited every year, and the performance benchmark is recalibrated in order to estimate the contribution of tree planting which is additional.

Based on the year of planting, trees are separated into existing trees (planted before the *Acorn Project Period*) and additional trees (planted during the *Acorn Project Period*). The existing trees are used for establishing dynamic baseline while the additional *trees* are used to establish the percentage contribution of *pre-existing vs newly planted trees*. Combined they are used to estimate an adjustment factor and demonstrate additionality.

Finally, sensitivity analysis are performed, where tree or stand parameters as well as the number of plots and reference data are adjusted. Additionality is assessed by simulating one-year prediction of biomass in three scenarios: 1) No implementation of agroforestry design; 2) Full implementation of agroforestry design; 3) Double implementation of agroforestry design. The different scenarios are developed to simulate the additionality that Acorn brings, by simulating the likelihood of newly planted trees to have negative to no impact on the project area.

2 Sources

This module applies the following Acorn Module:

- **AM-001** Methodology for Quantifying Carbon Benefits from Small-scale Agroforestry v2.0
- **AM-003** Module for Ground Truth Sampling v1.0

3 Definitions

Definitions used in this module follow the latest version of the Acorn Glossary available on the Acorn website.

4 Applicability Conditions

The method described in this module is globally applicable, as the implemented features are available for every *ecoregion* and are applied to a specific *Acorn project*. For this module, the applicability conditions of the Acorn Methodology **AM-001 v2.0** should be met.

5 Procedures

The method of the pre-project tree adjustment model is based on two parts:

1. Selection of *Control plots data* following representative stratified systematic sampling strategy.
2. Modeling the *Aboveground Biomass (AGB)* growth of individual trees within an *Acorn project*, based on *Control plots data* (tree species, year of planting), by generating growth curves of the tree species.
3. Using the growth curve models determined in (1), tree species, and *Agroforestry Design* to estimate the percentage of *pre-existing biomass* growth from total biomass to calculate the adjustment factor.
4. Perform sensitivity analysis to simulate yearly prediction of biomass growth as a result of implementation of agroforestry, to establish additionality of Acorn program. The analysis is performed yearly on three scenarios: 1) no implementation of agroforestry design, 2) full implementation of agroforestry design; 3) over implementation of agroforestry design.

5.1 Input data

5.1.1 Ground truth plots (tree species biomass)

Tree species information is derived from the *ground truth plot measurements* collected for each *Acorn project* (see ***AM-003*** *Module for Ground Truth Sampling* for more detail). Once *ground truth plots data* is collected, the *Acorn program* follows a data-cleaning and preparation protocol to ensure high quality data.

The tree *biomass* output that is generated after the data preparation steps, contains information for all trees that are detected and measured through the *ground truth plots measurement* procedures. Information such as the species name of each tree, the *plot* id, the year the tree is planted, the tree height, and the *Aboveground Biomass* are some of the information that can be found in the tree *biomass* file.

5.1.2 Sub-selection of control plots

From the full set of *ground truth plots data*, minimum of 30 *sub-plots* per project are selected as *control plots*. The same approach as in AM-003 is followed, however while for biomass model calibration, all classes have to be equally represented to avoid bias towards low or high biomass, here the proportion of control plots in each class has to be representative for the proportion of plots in each class.

5.2 Generate AGB growth curves

The type of function used to model all tree growth curves is sigmoid. This 's-shaped' growth curve is a well-established representation of plant species growth (Pödör et.al., 2014; Seo et al., 2023; Weiner & Thomas 2001; Yix et.al., 2003; Zeide 1993), having been tested on various tree datasets. The key features of real-world tree growth that are well captured by the sigmoid function are 1) an initial slow growth; 2) a strong increase in growth rate (with maximum growth at the sigmoid mid-point); 3) a later strong decrease in growth rate, resulting in a maximum *biomass* reached (long before the tree dies) as presented in Figure 1.

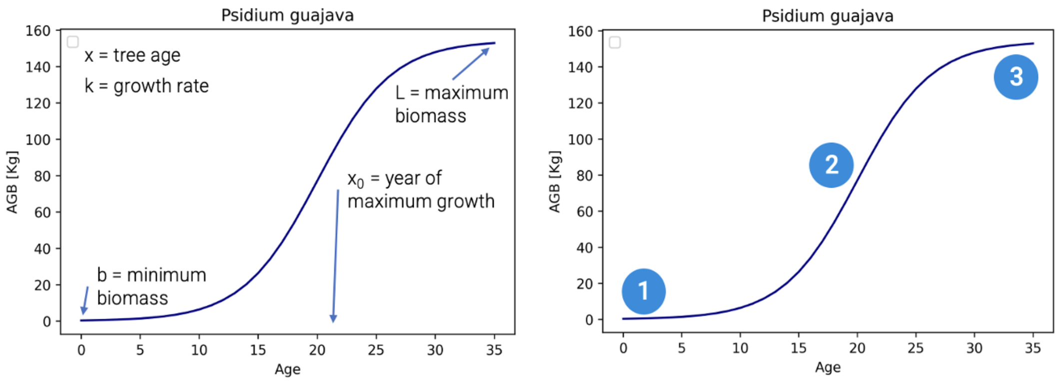

Figure 1: Tree growth features by the sigmoid

Equation 1 is used to calculate the Sigmoid AGB growth curves.

$$y = \frac{L}{1+\exp(-k(x-x0))} + b$$

Equation 1

Where:

y = Above-ground biomass of an individual tree (in kg)

L = The maximum *biomass* (tonne) that a tree species can reach

k = The growth rate of a tree species

x = The tree age

$x0$ = The year of maximum growth (relative) of a tree species

b = The minimum *biomass* (tonne, close to zero) that a tree species can reach

The input data that is used to generate the growth curves per tree species are:

- *Aboveground Biomass* of all trees from all species
- Age of all trees from all species

To construct the growth curves per species we follow the next steps:

1. Group all trees of a species based on the tree age.

2. Extract the median value (50% quantile) of the *Aboveground Biomass* of all trees that belong to each tree age group.
3. Sigmoid curve fit–generate curve by finding the best sigmoid fit to the series of the given data points by using non-linear least squares and constructs the growth curve. Evaluation is performed by multiple iterations, to select the optimal parameters of the best fit by using the RSS (residuals sum of squares) as a metric, that describes the variance of the residuals. The parameters that produce the lowest RSS are the ones that are selected as the optimal parameters.

The parameters that are used in the curve fitting method are the following:

- Maximum number of evaluations for optimal parameters: 1000
- Algorithm to minimize influence of outliers, for example trust region reflective.
- Boundaries for the optimal parameters:
    - Maximum *Aboveground Biomass* a species can reach (L): 0-10 tonne.

  - Age when the maximum growth (or maximum curve steepness) can be observed (*x*0): 5-30.
  - Steepness of the growth curve (*k*): 0-2.
  - Minimum *Aboveground Biomass* a species can reach at the baseline (*b*): 0-0.005 tonne.

The output must contain:

- Name: species name for species specific curve.
- Maximum age of the trees that are used to generate the growth curves.
- Optimal parameters.
  - Maximum *Aboveground Biomass* a species can reach (*L*)
  - Age when the maximum growth (or maximum curve steepness) can be observed (*x*0)
  - Steepness of the growth curve (*k*)
  - Minimum *Aboveground Biomass* a species can reach at the baseline (*b*)
- Number of tree-age groups used for each species.

The section below describes the two different tree AGB growth curves types (species specific and generic curves), when they are selected and how they are generated to model the tree AGB growth.

5.2.1 Species specific AGB growth curve

To generate a tree specific AGB growth curve, a set of criteria from the tree *biomass* file should be met. The tree species that do not meet this set of criteria qualify for a generic AGB growth curve. The set of criteria for the generation of a tree specific AGB growth curve are the following:

- Tree species data availability within tree age groups: Tree age 0-40 years, split into 8 groups of 5 years each. For every tree species, minimum of one point to at least 4 of these groups (50% tree data coverage).
- Minimum number of data points required for a tree species is 8: There should be at least 8 trees detected of a certain species, which is considered sufficient (Chave et.al., 2014, Pödör et.al., 2014, Seo et al., 2023).
- Minimum age of the oldest tree for a tree species is 15 years and maximum age of the youngest tree for a tree species is 5 years.
- Maximum tree age of a tree species is 40 years.

Example: A sigmoid fit example is shown in Figure 2. In this example, ~32 trees of *Cordia africana* tree species are used to generate the fit. The R2 value is determined by comparing the data of the *Cordia africana* species with its best-fit sigmoid curve and it gives an indication of how accurate the data of this species resemble a true sigmoid. This R2 is later used as another metric to determine whether a tree species gives a reasonable tree-specific fit or whether a generic curve needs to be generated instead.

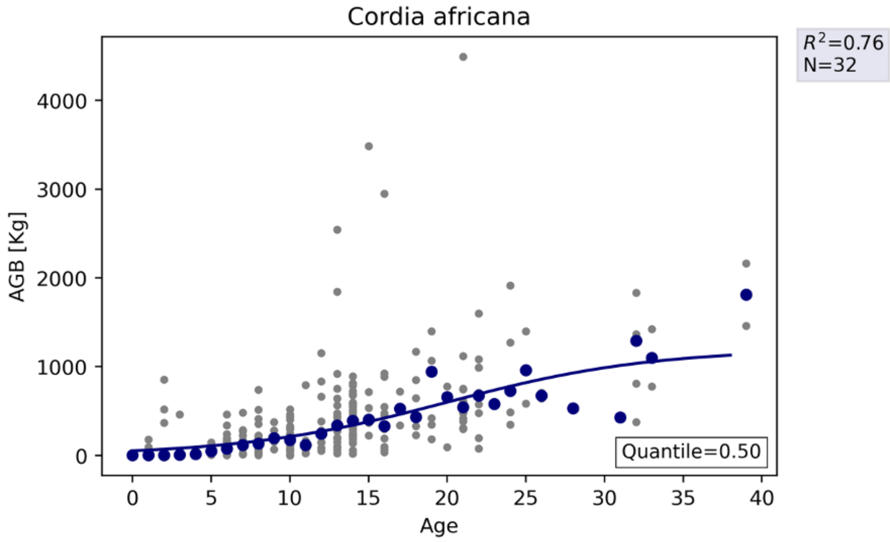

Figure 2: Example of sigmoid fit for Cordia Africana trees for an Acorn project. Blue dots indicate the median (50th quantile) per year of age, that are used as input to the sigmoid fit.

When the species-specific sigmoid is generated, the following criteria need to be met in order to accept the sigmoid:

- Slope of the sigmoid fit is positive.
- Fitting curve starts at *Aboveground Biomass* smaller than 5 (tonne/ha). Median biomass of trees in the oldest age class is within 30% of maximum sigmoid *biomass*.
- R2 of sigmoid fit is greater than 0.25.

If one of the criteria above is not met for a certain tree species, a generic curve is generated instead.

5.2.2 Generic AGB growth curve

The tree species that do not qualify for a tree-specific AGB growth curve, are considered as separate tree species. Data points (tree age and AGB) are taken from all trees belonging to this category in order to construct a AGB growth curves for these species. This growth curve is called Generic AGB growth curve and the steps for its generation are the same as the tree specific AGB curve, described in Section 5.2.

5.3 Model total AGB growth (pre project plus additional) after Acorn project intervention

The modelling of the tree AGB growth of all trees from the Control plots by using the tree-specific and the generic AGB growth curves. This includes both existing trees and those part of the *Agroforestry design*.

5.4 Estimate percentage of pre-project tree AGB growth (EETB)

When the expected total tree AGB growth is estimated per *Control plots plot*, the pre-project tree from the additional tree AGB growth (by *Acorn* project intervention) are separated, based on the year of planting and the start year of an *Acorn project*. Figure 3 shows the pre-project, additional and total AGB growth for a *project* after the *project* start and identifies the EETB in different periods. This percentage of pre-project tree *AGB* growth (EETB) is estimated by considering all *Control plots* from a project location, by using Equation 2:

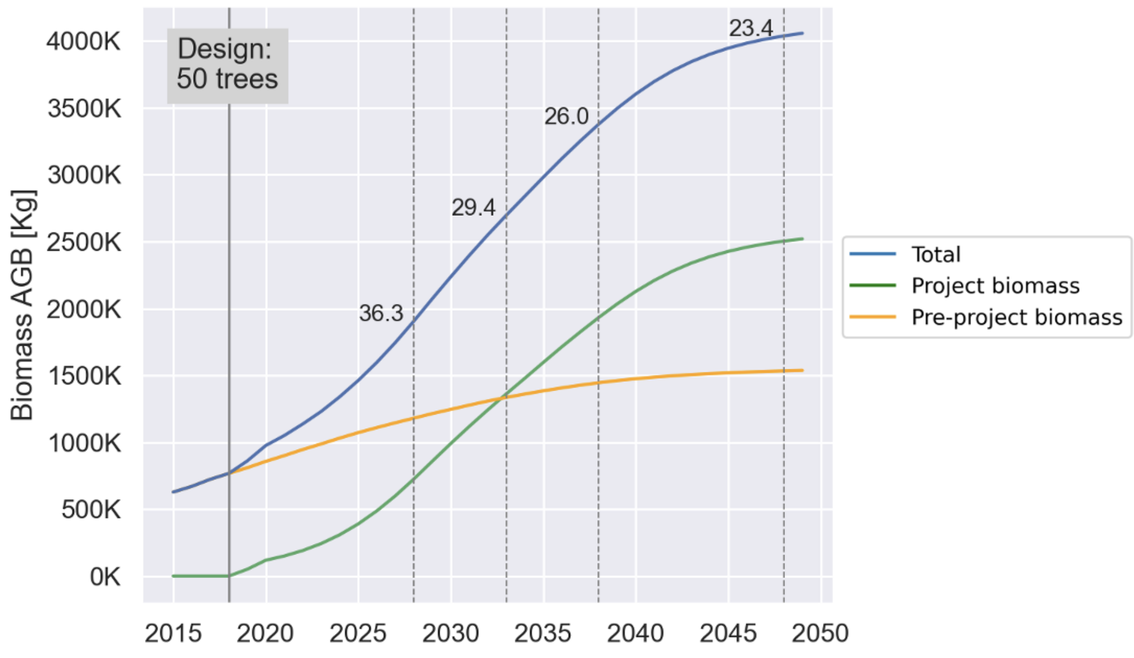

Figure 3. Example of the pre-project AGB and the project (Acorn) AGB growth over the years, when planting 50 trees in 2018.

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

Equation 2

Where:

$EETB_{s,y}$	= Estimated pre-project AGB in stratum s in year y*EETB*$_{y,s}$
$ETB_{s,y=0}$	= Pre-project AGB in *stratum s* at the start year *y* of the project
$TB_{s,y}$	= Total AGB in *stratum s* in year *y*
n	= Number of sample plots in *stratum s*

5.5 Calculate adjustment factor:

1. Estimate the percentage *uncertainty* of If $EETB_{y,s}$ at 90% confidence level, by using Equation 3

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

Equation 3

Where:

$U_{EETB_{s,y}}$	= Estimate the percentage *uncertainty* of EETB$_{y,s}$
$EETB_{s,y}$	= Estimated pre-project AGB in *stratum s* in year *y*
σ	= Standard deviation of all *control plots* $\left(\frac{(ETB_{s,y}-ETB_{s,y=0})}{(TB_{s,y}-ETB_{s,y=0})} \cdot 100\right) i$
n	= Number of sample plots

2. Adjust for the *uncertainty* of $EETB_{s,y}$ by using Equation 4

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

Equation 4

Where:

$AdjU_{EETB_{s,y}}$ = Adjustment for uncertainty of $EETB_{y,s}$ in stratum s in year y.

$U_{EETB_{s,y}}$ = Uncertainty at 90% confidence level. $EETB_{s,y}$

3. Calculate adjustment factor for baseline removal for all *plots* in a *project area*. Steps 1 and 2 are considered and the adjustment factor is estimated based on Table 1.

Table 1: Overview of the baseline removal adjustment factor

Estimated change in existing tree biomass in stratum *s* after adjustment for uncertainty (*EETB*$_{s,y}$ + *AdjU*$_{EETBs,y}$)	**Adjustment factor for baseline removal in stratum *s* (*AdjB*)**		
	Low class	Medium class	High class
$(EETB_{s,y} + AdjU_{EETB_{s,y}})$≤ 10%	0%	0%	0%
10% < $(EETB_{s,y} + AdjU_{EETB_{s,y}})$ ≤ 25%	7,5%	10%	12,5%
25% < $(EETB_{s,y} + AdjU_{EETB_{s,y}})$ ≤ 50%	18,75%	25%	31,25%
50% < $(EETB_{s,y} + AdjU_{EETB_{s,y}})$ ≤ 75%	37,5%	50%	62,5%
75% < $(EETB_{s,y} + AdjU_{EETB_{s,y}})$ ≤ 90%	53%	70%	97%
$(EETB_{s,y} + AdjU_{EETB_{s,y}})$ > 90%	100%	100%	100%

5.6. Allocation of pre-project tree based on project baseline

To ensure a fair distribution on the adjustment factor on plot level, the following implantation steps are applied:

1. Estimate of baseline vegetation estimation at the start of the project using NDVI range.
2. Classify the project area into 3 biomass classes (low, medium and high) and allocating the farmer plots to each class
3. Estimate Adjustment factor on GT at time of farmer onboarding
4. Distribute Adjustment factor among the 3 classes, where the highest class gets the highest % adjustment, the lowest class the lowest %, however, the sum equals the project adjustment as following Table 1 above
5. Recalculate of the classes and adjustment factor % takes place on yearly basis during the measuring period when additional farmer plots and Control plots are added.

5.7 Demonstrating Additionality

Sensitivity analysis are performed, where tree or stand parameters as well as the number of plots and reference data are adjusted. Additionality is assessed by simulating one year prediction of biomass in three scenarios:

1) No implementation of agroforestry design;

2) Full implementation of agroforestry design;

3) Double implementation of agroforestry design.

The different scenarios are developed to simulate the additionality that Acorn brings, by simulating the likelihood of newly planted trees to have negative to no impact on the project area. Student t-test is performed to establish the statistical significance of biomass change in comparison to the predicted value. Additionality is demonstrated after the predicted values from the scenarios are validated.

5.8 Model Assumptions

Category	Assumption	Explanation
General – *Control plots data*	Control plots tree data is reliable (except for obvious outliers, which are removed) [Acorn Methodology]	The accuracy of the modeling and projections relies on the accuracy of the *Control plots data*, especially tree age (year of planting) and input values for *Aboveground Biomass* calculation (height, DBH, etc.).
Tree models - theory	Allometric equations describe *Aboveground Biomass* per tree species well.	[Acorn Methodology]
Tree models - sigmoid	Growth of all tree species is represented by a sigmoid.	Sigmoid functions represent tree growth well (see above). However, some trees might not grow exactly as a sigmoid, or at least not for the entire growth period. Trees with growth curves that deviate from the sigmoid shape will affect the accuracy of the model.

Projections - sampling	*Control plots data* for visited *plots* is representative of all *plots*.	[Acorn Methodology]
Projections – *Agroforestry Design*	The *Agroforestry Design* is implemented as expected, for all *plots* in the *Acorn project*.	The *Agroforestry Design* is an average of the expected implementation over all *plots* within a *project area*. If the design is not an accurate average, e.g., if all farmers plant only one type of species, then the results deviate from projections.
Projections – *Agroforestry Design*	Survival rate of planted trees is reliable.	The *Agroforestry Design* takes the survival rate of trees into account. *Uncertainties* or changes in the survival rate over time would not be captured by the projections.
Projections – minimum *plot* area	The provided farm area is used entirely for planting trees according to the design, rounded to 0.05 ha.	For calculation of the number of newly added trees in the design, a rounded value of the provided farm area is used. If not the entire farm area is being planted, estimations may deviate from the true values.
Projections – *ecoregion*	Growing conditions within an *ecoregion* are similar.	The models are generated per *ecoregion* (based on WWF classification) as per Acorn Methodology **AM-001 v2.0**. This implies that conditions are stable within the *ecoregion*.
Projections	Current project conditions (e.g. climate, soil quality, tree density, pruning practices, etc.) are assumed to be constant throughout the projected period and overall *plots* within the *Acorn project*.	While the data-driven approach implies that project conditions are by definition built into the models, potential changes in these conditions are not accounted for. Therefore, if conditions change significantly during the projected period, then the true *biomass* growth over time may deviate from the predicted values (because the parameters of the sigmoid may change).

Projections	Singular events such as disease outbreaks or fires are not accounted for by the modeling.	One-off events cannot be taken into account. The *Acorn program buffer pool* is set up for this purpose.

6 Parameters

Data/Parameter	b
Units	Tonne/ha
Description	Minimum *biomass* (t CO_2e close to zero)
Equations	Equation 1
Source	Derived from literature sources ed in bibliography for each species
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	The parameter is required in order to build a representative model
Purpose of Data	Use to build the growth curve
Comments	N/A

Data/Parameter	ETB_y, $ETB_{s,y=0}$
Units	Tonne/ha
Description	Pre-project *biomass* in *stratum s* in year *y* or at the start of the *Acorn Project Period* (tonne/ha)
Equations	Equation 2
Source	*Control plots data* collection and allometric equation(s)
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	The parameter is required to build a representative model
Purpose of Data	Calculation for determining the value of existing *biomass* in pre-project trees
Comments	N/A

Data/Parameter	k

Units	% per year
Description	Growth rate
Equations	Equation 1
Source	Derived from literature for each tree species
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	The parameter is required in order to build a representative model
Purpose of Data	Used to build the tree-specific growth curve
Comments	N/A

Data/Parameter	L
Units	Tonne/ha
Description	Maximum *biomass* (tonne/ha)
Equations	Equation 1
Source	Derived from literature for each tree species
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	The parameter is required in order to build a representative model
Purpose of Data	Used to build the tree-specific growth curve
Comments	N/A

Data/Parameter	n
Units	No unit
Description	Total number of *sample plots*
Equations	Equation 2
Source	**AM-003**
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	*Sample plots of which Control plots data is collected.*
Purpose of Data	Development and performance assessment of model for estimating *biomass* from satellite imagery
Comments	N/A

Data/Parameter	$TB_{s,y}$
Units	Tonne/ha
Description	Total *aboveground biomass* in *stratum s* in year *y* (tonne/ha)
Equations	Equation 2
Source	*Control plots data* collection and allometric equation(s)
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	The parameter is required in order to build a representative model
Purpose of Data	Calculate appropriate adjustment factor for growth of pre-project trees
Comments	N/A

Data/Parameter	x
Units	Year(s)
Description	Tree age
Equations	Equation 1
Source	Derived from *Control plots data*. Farmers are asked about the tree age(s) when collecting *Control plots data*. If age is unknown farmer together with the data collector estimate the tree age.
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	Used to build growth-curves
Purpose of Data	
Comments	N/A

Data/Parameter	x_0
Units	Year
Description	The year of max growth (relative)
Equations	Equation 1
Source	Modelled based on tree species type and *Control plots data*
Value	N/A
Justification of choice of data or description of	N/A

measurement methods and procedures applied	
Purpose of Data	Predict *biomass* growth
Comments	N/A

Data/Parameter	σ
Units	Tonne/ha
Description	Standard deviation of all Control plots.
Equations	Equation 3
Source	Analysis of *Control plots data*
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	Standard deviation is used to calculate the *confidence interval*
Purpose of Data	Calculation of *confidence interval* needed to determine *uncertainty* adjustment factor for the *Acorn project*
Comments	N/A

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