AM 005

Module for Determining Adjustment Factor for Change in Pre-project Tree Biomass inSmall-scale Agroforestry

Version 1.0 – October 2024

Acorn

Contents

1 Summary

This module provides a method for the increase in *biomass* of trees present in the *project area* prior to the start of the *Acorn Project Period*, and the relevant adjustment factor to apply when calculating CRUs

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* within a 30-year period. Accordingly, an appropriate adjustment factor (AdjB) must be selected from Table 1 to apply on a project-level. The output of the module (AdjB) is used within the Acorn Methodology **(AM-001 v2.0)** to calculate CRUs.

The input parameters are derived from a subset of *plots*, used for field measurements, also referred to as ground truth *plots*. These parameters include but are not limited to trees with a height above 1.3 meters, species names, year of planting, and *biomass* per hectare. A species-specific sigmoid-based growth curve is applied to each individual tree. 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 to construct an accurate growth curve, a growth curve is constructed based on theoretical information and/or ground measurements from comparable projects.

For each *sample plot*, the *biomass* change is estimated for the duration of 30 years, based on the species growth curves (or general growth curve if no specific curve could be constructed). The *Agroforestry Design* trees are compared with the *ground truth measurements*. If tree species, listed in the *Agroforestry Design* are not present within the *sample plots*, these are also added to the model. 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 Crediting Period*). The existing and additional *biomass* are combined to estimate whether adjustment for *pre-existing biomass* is required.

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. Modeling the *Aboveground Biomass (AGB)* growth of individual trees within an *Acorn project*, based on *ground truth data* (tree species list), by generating growth curves of the tree species.
2. Using the growth curve models determined in (1), tree species list, and *Agroforestry Design* to estimate the percentage of *pre-existing biomass* growth over 30 years after the start of the *Acorn Project Period* and calculate the adjustment factor.

Figure 1 shows the steps followed in the pre-project tree adjustment factor.

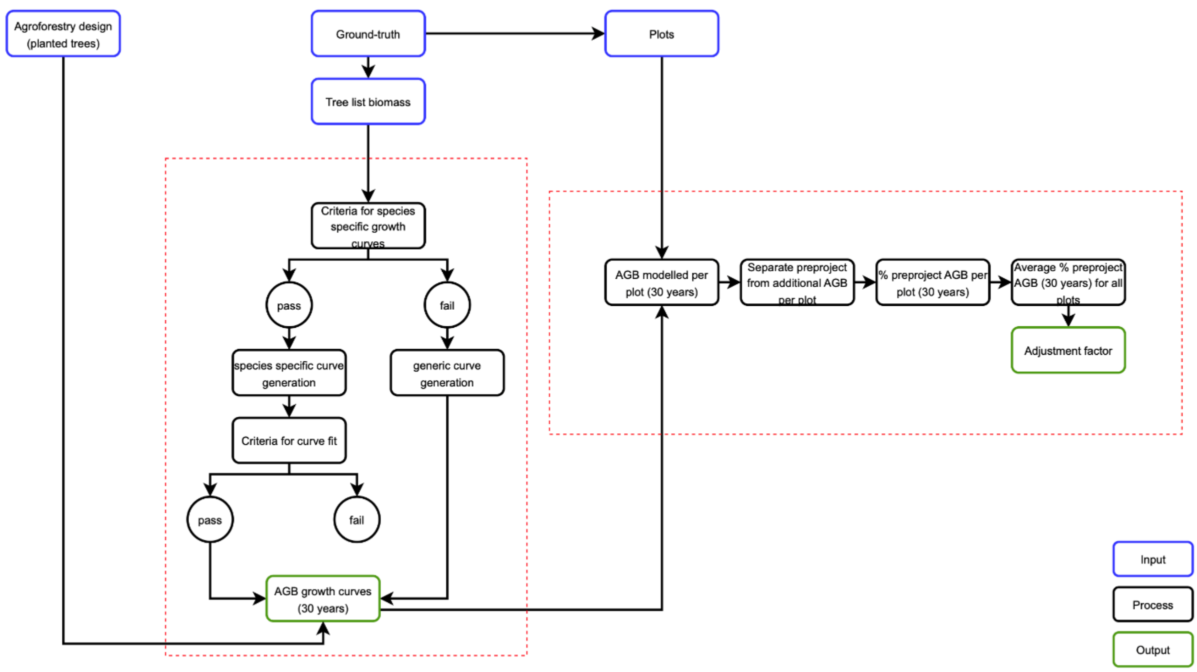

Figure 1: Flowchart of pre-project tree adjustment model steps

5.1 Input data

5.1.1 Ground truth (tree species list biomass)

Tree species list information is derived from the *ground truth measurements* collected for each *Acorn project* (see ***AM-003*** *Module for Ground Truth Sampling* for more detail). Once *ground truth data* is collected, the *Acorn program* follows a data-cleaning and preparation protocol, which prepares this data to be ready for use for the pre-project tree adjustment model.

The tree list *biomass* file that is generated after the data preparation steps, contains information for all trees that are detected and measured through the *ground truth 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 list *biomass* file.

5.1.2 Agroforestry Design

The *Agroforestry Design* contains the following information:

- Which tree species will be planted on the *agroforestry plots* for each *Acorn project*
- The year(s) when trees from the *Acorn project* will be planted
- The amount of trees that will be planted per hectare of every *plot* in every year
- Information on the silvicultural management practices

The *Agroforestry Design* considers trees that can be planted on each *plot*, the project location based on the "compatibility" of each newly planted tree, the geographical and climatic conditions of each project location, and the survival rate of each one of the different tree species.

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 2.

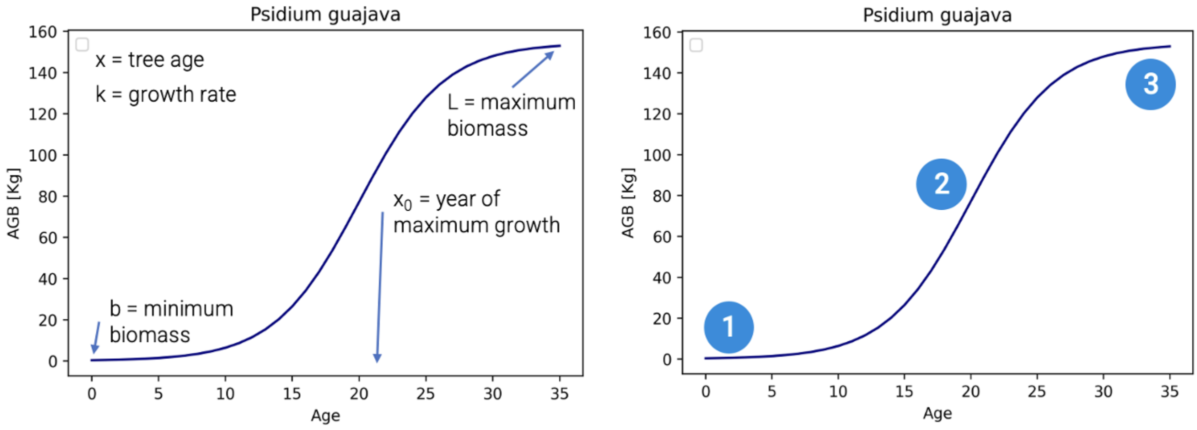

Figure 2: Tree growth features by the sigmoid

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. The reason why we choose the 50% quantile is that usually there are more young trees than old trees in the datasets. Using the raw data could result in unrealistic growth curves because the sigmoid fit would attempt to capture patterns in the noise of the young trees instead of attempting capturing the growth pattern from different years.
3. Sigmoid curve fit–generate curve. The curve fitting method that is used finds the best sigmoid fit to the series of the given data points by using non-linear least squares and constructs the growth curve. The method evaluates the curve fit of multiple iterations and it selects 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 (“maxfev”): 1000
- Algorithm to minimize influence of outliers (“method”): “trf” (trust region reflective) algorithm is used. It is considered as a robust method, and it is the default when value boundaries are given.
- 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.

When the optimal parameters are estimated per tree species they are exported in a csv format.

The columns of the output file are:

- Name: species name for species specific curve.
- MaxAge: maximum age of the trees that are used to generate the growth curves.
- popt: 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*)
- N: 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 list *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 bins: We split the tree age (0-40 years) into 8 bins of 5 years each. For every tree species, we should have at least one point to at least 4 of these bins (50% tree data coverage). This is displayed in Figure 3. This data coverage threshold is chosen based on experience of examining many fits for many different species, aiming to find a reasonable balance between obtaining a good data coverage threshold and minimizing the number of species modeled with a generic growth curve.
- Minimum number of data points required for a tree species is 8: There should be at least 8 trees detected of a certain species. According to Chave et.al., 2014, Pödör et.al., 2014, Seo et al., 2023, limited amount of data points (around 8) is sufficient for modelling tree growth.
- 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. After testing multiple sigmoid fits, these values, in combination with the data coverage threshold, cover the growth spectrum of a tree species and can provide a robust tree-specific AGB growth curve
- Maximum tree age of a tree species is 40 years. This tree age threshold is chosen, because growth curves flatten out after 30 years, so fitting the sigmoid over much larger timescales is not necessary.

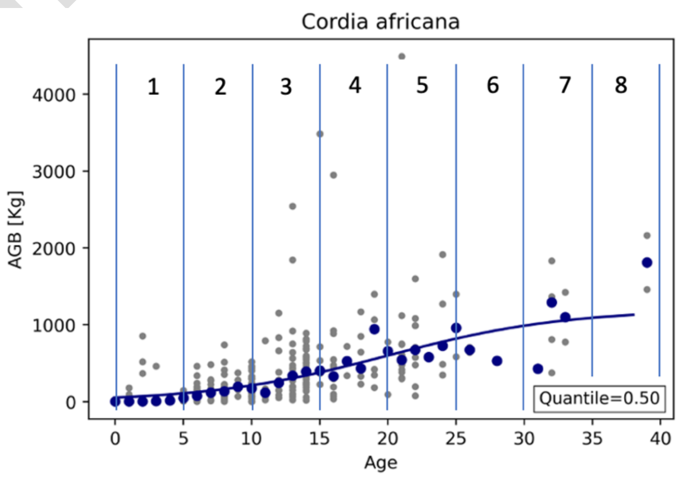

Figure 3: Display of age bins for a sigmoid fit for Cordia Africana trees for a certain project.

A sigmoid fit example is shown in Figure 4. 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.

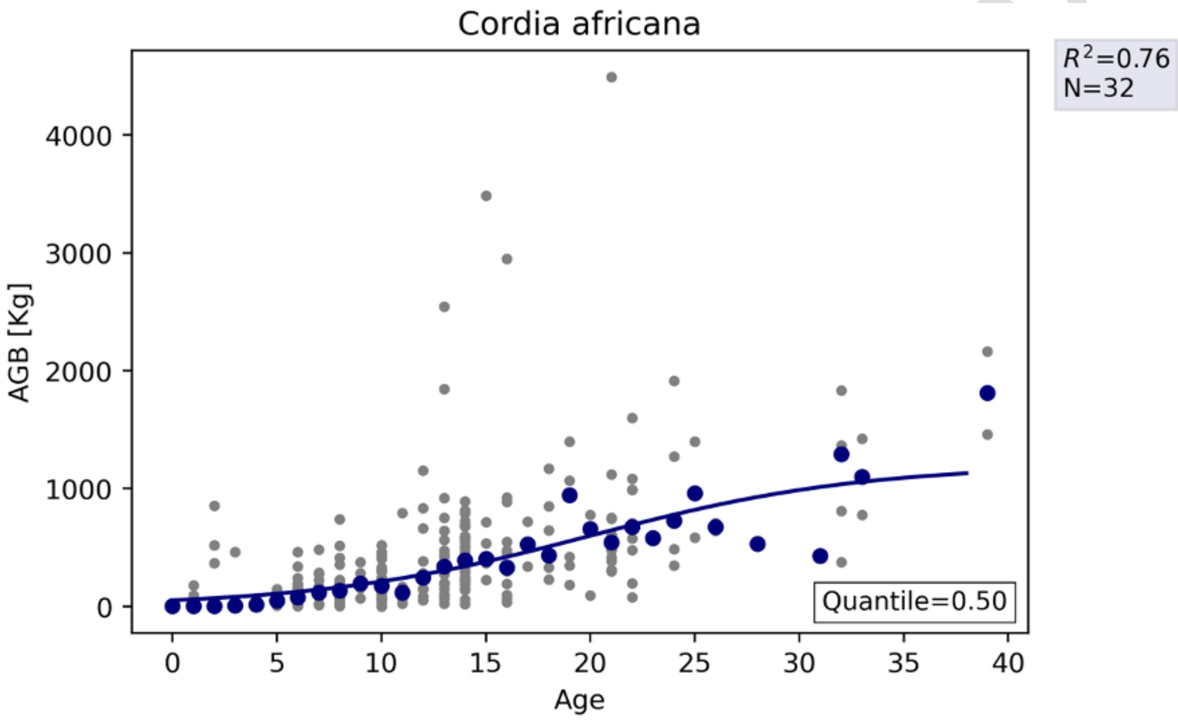

Figure 4: Example of sigmoid fit for Cordia Africana trees for an Acorn project. Blue dots indicate the median (50th quantile) per year of age, that are used as input to the sigmoid fit.

When the species-specific sigmoid is generated, the following criteria are checked to determine whether the sigmoid generates a reasonable fit for all tree species:

- 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. The above criteria are selected based on extensive testing of various datasets as they were found to provide an optimal trade-off between obtaining tree-specific curves with realistic fits and minimizing the number of species modelled with a generic curve. 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 separate tree species altogether. Data points (tree age and AGB) are taken from all trees belonging to this separate "tree species category" in order to construct a AGB growth curves for this 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 (1. group trees based on age, 2. extract median AGB value per age group, 3. Generate the sigmoid AGB growth curve).

Like for the tree specific AGB growth curves generation the Generic curves' optimal parameters are stored at the same csv file, so that it can be used in the next steps of the process.

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 ground truth *plots* and the *Agroforestry Design* is the next step of the process, by using the tree-specific and the generic AGB growth curves. We check if a tree-specific growth curve is available for all the newly planted trees from the Agroforestry Design. If for some species there is not, a generic curve is used for these species. The next step is to estimate the total AGB, from all trees (pre project plus additional) for every single *ground-truth* plot, 30 years after the *Acorn* project intervention. The reason why we 30 years period is used is that the AGB growth of trees at this age becomes relatively stable, so AGB is not expected to grow after this 30 years period.

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

When the expected total tree AGB growth is estimated per *ground truth plot*, we separate the pre-project tree from the additional tree AGB growth (by *Acorn* project intervention), by using the year of planting of each tree compared to the start year of an *Acorn project*. Figure 5 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 *ground truth plots* from a project location, by using Equation 2:

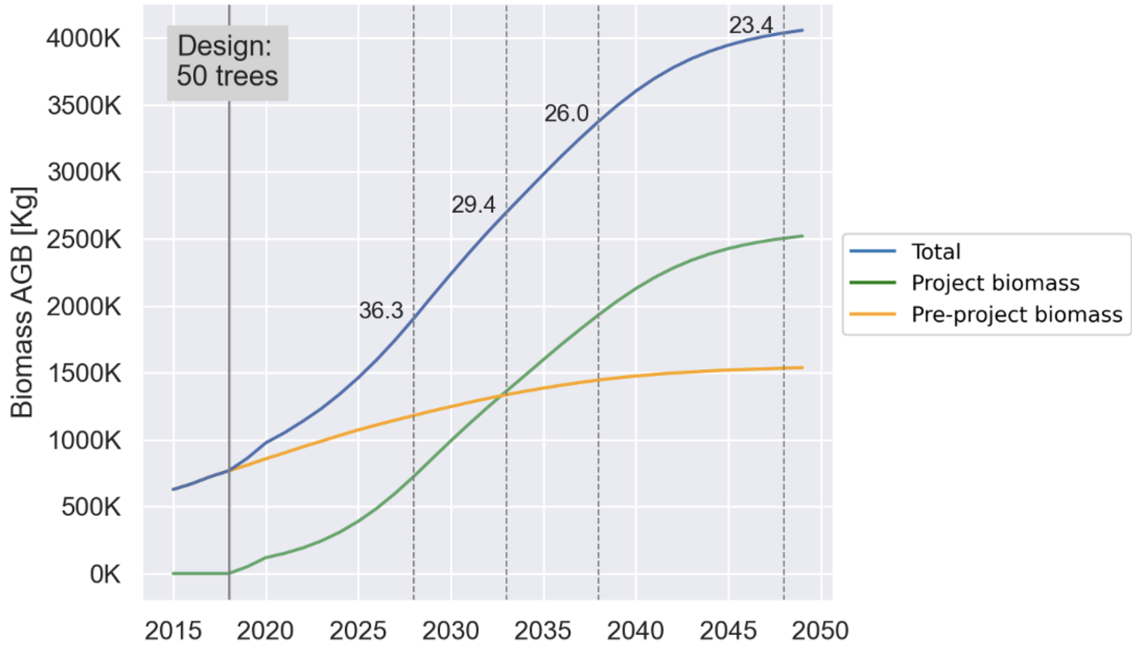

Figure 5. Example of the pre-project AGB and the project (Acorn) AGB growth over the years, when planting 50 trees in 2018.

This percentage of expected existing *biomass* growth (EETB) is estimated per *Acorn project*, using all *plots* on an *Acorn project*, by using Equation 2.

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

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

In order to calculate the adjustment factor we follow the following 3 steps:

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 *ground-truth 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. Estimating of baseline vegetation estimation at the start of the project using NDVI range.
2. Classifying the project area into 3 biomass classes (low, medium and high) and allocating the farmer plots to each class
3. Estimating Adjustment factor on GT at time of farmer onboarding
4. Adjustment factor is distributed 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. Recalculation of the classes and adjustment factor % takes place on yearly basis during the measuring period when additional farmer plots and ground truth plots are added.

5.6 Modeling assumptions

Category	Assumption	Explanation
General – *ground truth data*	Ground truth 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 *ground truth 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	*Ground truth 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 listed 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	*Ground truth 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 ground truth 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	*Ground truth 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 *ground truth data*. Farmers are asked about the tree age(s) when collecting *ground truth 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 *ground truth data*
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Predict *biomass* growth
Comments	N/A

Data/Parameter	σ
Units	Tonne/ha
Description	Standard deviation of all ground truth *plots*.
Equations	Equation 3
Source	Analysis of *ground truth 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

7 References

Chave, J. *et al.* (2014) 'Improved allometric models to estimate the aboveground biomass of tropical trees,' *Global Change Biology*, 20(10), pp. 3177–3190. https://doi.org/10.1111/gcb.12629.

Pödör, Z., Manninger, M. and Jereb, L. (2014) 'Application of sigmoid models for growth investigations of forest trees,' in *Advances in intelligent systems and computing*, pp. 353–364. https://doi.org/10.1007/978-3-319-06569-4_26.

Seo, Y., Lee, D. and Choi, J. (2023) 'Developing and comparing individual tree growth models of major coniferous species in South Korea based on STEM analysis data,' *Forests*, 14(1), p. 115. https://doi.org/10.3390/f14010115.

Weiner, J. and Thomas, S.C. (2001) 'The nature of tree growth and the "age-related decline in forest productivity",' *Oikos*, 94(2), pp. 374–376. https://doi.org/10.1034/j.1600-0706.2001.940219.x.

World Agroforestry Centre | agroforestry database 4.0 (no date). https://apps.worldagroforestry.org/treedb/.(Accessed: October 24, 2023).

Yin, X. *et al.* (2002) 'A flexible sigmoid function of determinate growth,' *Annals of Botany*, 91(3), pp. 361–371. https://doi.org/10.1093/aob/mcg029.

Zeide, B. (1993) 'Analysis of growth equations,' *Forest Science*, 39(3), pp. 594–616. https://doi.org/10.1093/forestscience/39.3.594.