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The AFOLU Carbon Calculator

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THE AFFORESTATION/ REFORESTATION TOOL: UNDERLYING DATA AND METHODS

Winrock International

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TABLE OF CONTENTS

List of Figures....3
List of Tables....3
1. Scope....4
2. Applicability....4
3. Approach to the A/R tool....4
4. Data Sources....4
4.1. Tropical Native Forests....4
4.2. Mangrove Forests....5
4.3. Plantation Forests....6
5. Uncertainty of Estimates....6
5.1 Combining uncertainties for multiplication....8
5.2 Combining uncertainties for addition and subtraction....9
6. Calculation Methods....10
6.1. Chapman-Richards Model....10
6.2. Tropical Native Forests....11
6.3. Mangrove Forests....12
6.4. Plantation Forests....13
6.5. Hypothetical Example....14
7. Overriding Default Data....15
8. References....15
ANNEX I-Native tropical forests....19
ANNEX II--Mangroves....21
ANNEX III--Plantations....22

LIST OF FIGURES

Figure 1: Aboveground biomass accumulation curve for Rain Forest, fitted using 107 data points taken from 20 studies of secondary forest . Upper and lower curves represent upper and lower bounds of 95% CI. 11
Figure 2: Aboveground biomass accumulation curve for Moist Forest, fitted using 70 data points taken from 9 studies of secondary forest. Upper and lower curves represent upper and lower bounds of 95% CI. 11
Figure 3: Aboveground biomass accumulation curve for Dry Forest, fitted using four data points taken from two studies of secondary forest. Upper and lower curves represent upper and lower bounds of 95% CI. 12
Figure 4: Aboveground biomass accumulation curve for A/R mangrove forest, fitted using 18 data points taken from eight studies of A/R mangroves. Upper and lower curves represent upper and lower bounds of 95% CI. 13

LIST OF TABLES

Table 1 Key parameters used to estimate the carbon benefits of afforestation / reforestation and an assessment of their uncertainties........ 8
Table 2 Literature based growth parameters for estimating biomass accumulation in tropical forests using a Chapman-Richards logistic growth equation........ 12
Table 3 Tree species available in the A/R Tool per climate type and their respective modeled parameters based on the Chapman-Richards equation. 14
Table 4 Key information on literature about aboveground biomass of secondary tropical forest compiled for developing growth models under the A/R tool. Values reported in literature are rounded to nearest ton here. 19
Table 5 Key information on mangrove biomass literature compiled for developing growth models under the A/R tool. 21
Table 6 Tree species available per climate zone that can be selected in the A/R tool........ 22

1. SCOPE

This document describes the underlying data sources and calculation methods employed in the Afforestation/Reforestation (A/R) Tool of the AFOLU Carbon Calculator (http://afolucarbon.org/). The A/R Tool is designed for project activities that aim at sequestering atmospheric carbon by planting forests in non-forested areas.

2. APPLICABILITY

This A/R Tool is applicable to afforestation or reforestation activities that will sequester and store atmospheric carbon. The forestation activities can be composed of plantings of heterogeneous native species or monocultures of a single species. Most of the key commercial species employed in silvicultural systems worldwide are included in the database.

Plantings of timber species along with agricultural species are not covered in this A/R Tool, but can be included by using the Agroforestry Tool.

3. APPROACH TO THE A/R TOOL

The approach employed in the A/R Tool reflects an improvement from the standard IPCC Tier 1 approach, in which biomass carbon accumulates linearly for the first 20 years, after which the rate declines to another lower constant rate. In the biomass accumulation rates are curvilinear directly correlated to the time since tree establishment (age in years).

The A/R Tool employs models based on the Chapman-Richards growth equation (Richards 1959; Pienaar and Turnbull 1973) to estimate the rate of aboveground biomass carbon accumulation in planted forests, whether for native or commercial species.

Data from published literature were compiled and the Chapman-Richards growth model applied to represent the rate at which carbon is sequestered in planted forests. The model captures slow carbon accumulation at earlier ages, increasing as the forests mature, and peaking and tapering off when a mature age is reached. The model's slope and inflexion points vary by species and climate type.

4. DATA SOURCES

4.1. TROPICAL NATIVE FORESTS

An extensive literature search was conducted on the topic of biomass accumulation in secondary tropical forests. Studies were included in the analysis only if details of the methodological approach, including description of methods, were included.

Information on average aboveground biomass stock of secondary forests was compiled from 31 selected studies conducted on tropical forest stands of various ages following abandonment of the previous land use. The study areas were categorized based on FAO ecological zones as follows:

- *Rain Forest:* Tropical rainforest with no real dry season
- *Moist Forest:* Tropical moist deciduous forest, subtropical moist deciduous forest, and tropical mountain forests
- *Dry Forest:* Tropical and subtropical dry forest

Studies were assigned to one of the three categories based knowledge of their location and precipitation regime (details of data are in Annex 1).

The average of plot level values for aboveground biomass at a given stand age from the studies provided data points for fitting the Chapman-Richards equation in the analyses. Data on total aboveground biomass were associated with the respective climate type and plotted against stand age. These data were used to derive values for the parameters *MAX*, *k* and *m* used in the Chapman Richards equation for estimating aboveground tree biomass as a function of age in secondary forests in Dry Forest, Moist Forest, and Rain Forest categories.

Below ground carbon stocks are derived using the following equation from Mokany et al (2006):

$$BGC = 0.489 * AGC^{0.890}$$

Where:

BGC = Below-ground carbon stocks (t C ha^{-1})

AGC = Above-ground carbon stocks (t C ha^{-1})

4.2. MANGROVE FORESTS

A literature review was conducted of published, peer-reviewed studies on the biomass accumulation rates of A/R mangrove forests across various geographical regions. Around a dozen studies were initially reviewed, but approximately half were discarded from the analysis due to issues with methodological approach and applicability (e.g. experimentation with species composition, flooding regimes, excavation of study sites, etc). Ultimately, eight studies on biomass accumulation in A/R mangrove forests were selected. These studies assessed the growth of an array of mangrove species at various ages, ranging from 2 to 28 years, conducted in seven geographical locations throughout the world. Data on aboveground biomass, belowground biomass, plantation age, and total biomass in tons of carbon per hectare (t C ha^{-1}) were aggregated and analyzed to develop a growth model (details of data are in Annex 2).

4.3. PLANTATION FORESTS

Data on growth parameters for various species planted commercially were summarized for 61 countries in FAO's Global Planted Forests Assessment (2005). We have cross-referenced the countries in the FAO database with the AFOLU Carbon Calculator database and selected the applicable species to such countries. The species available for A/R project activities per climate zone and data are given in Annex 3. The Mokany et al. (2006) equation described above is used to calculate the below-ground carbon stocks in the roots.

5. UNCERTAINTY OF ESTIMATES

Uncertainty is a property of a parameter estimate and reflects the degree of lack of knowledge of the true parameter value because of factors such as bias, random error, quality and quantity of data, state of knowledge of the analyst, and knowledge of underlying processes. Uncertainty can be expressed as the size of the half width of a specified confidence interval as a percentage of the mean value. For example, if the area of forest land converted to cropland (mean value) is 100 ha, with a 95% confidence interval ranging from 90 to 110 ha, we can say that the uncertainty in the area estimate is ±10% of the mean (from GOFC-GOLD 2013).

Uncertainty is an unavoidable attribute of practically any type of data including land area and estimates of carbon stocks and many other parameters used in the estimation of the AFOLU carbon benefits from activities on the land. Identification of the sources and quantification of the magnitude of uncertainty will help to better understand the contribution of each source to the overall accuracy and precision of the final estimate.

The proper manner of dealing with uncertainty is fundamental in the IPCC and UNFCCC contexts. The IPCC defines estimates that are consistent with good practice as those which contain neither over- nor underestimates so far as can be judged, and in which uncertainties are reduced as far as practicable. The first step in an uncertainty analysis is to identify the potential sources of uncertainty. Many sources are possible including measurement errors due to human errors or errors in calibration; measurement errors in the predictor variables; modelling errors due to inability of the model to fully describe the phenomenon; parameter uncertainty, and residual uncertainty; erroneous definitions or classifications that lead to double-counting or non-counting; unrepresentative samples; and variability resulting from the use of samples rather than censuses. In this section, the potential sources of uncertainty are identified and an assessment of their likely range of uncertainties used in the calculation of the carbon benefit in this tool is presented (Table 1). A brief primer of the steps involved in assessing total uncertainties for each carbon benefit estimate is provided with a couple of simple examples to demonstrate the process. These analyses are not provided in the tools.

The reader is referred to the GOFC-GOLD 2013 sourcebook for more details on all sources of uncertainty and how to reduce them. In general, with the use of current medium to high resolution remote sensing data, the suite of algorithms for interpreting the imagery, and the standard methods for accuracy assessment of the products, data on land cover and land cover change are likely to be relatively accurate for forest to non-forest, but less so for forest type of percent tree cover. Assessing uncertainties in the estimates of C stocks, and consequently of C stock changes (i.e. the emission factors), can be more challenging than estimating uncertainties of the area and area changes. This is particularly true for tropical forests which are often characterized by a high degree of spatial variability and therefore require additional resources to acquire samples that are adequate to produce accurate and precise estimates of the C stocks in a given pool.

In addition to the uncertainties associated with each parameter, when parameters are combined as in e.g. estimating emissions from combining area planted and carbon accumulation rates that vary by age, then overall error of the product will change. Uncertainties in individual parameter estimates can be combined using either (1) error propagation (IPCC Tier 1) or (2) Monte Carlo simulation (IPCC Tier 2). Tier 1 method is based on simple error propagation, and cannot therefore handle all kinds of uncertainty estimates. The key assumptions of Tier 1 method are (from GOFC-GOLD 2013):

- estimation of carbon emissions and removals is based on addition, subtraction and multiplication
- there are no correlations across parameters (or if there is, they can be aggregated in a manner that the correlations become unimportant)
- none of the parameter estimates has an uncertainty greater than about ±60%
- uncertainties are symmetric and follow normal distributions

However, even in the case that not all of the conditions are satisfied, the method can be used to obtain approximate results. In the case of asymmetric distributions, the uncertainty bound with the greater absolute value should be used in the calculation. The Tier 2 method is based on Monte Carlo simulation, which is able to deal with any kind of models, correlations and distribution. However, application of Tier 2 methods requires more resources than that of Tier 1.

The key parameters are low to medium uncertainty, with high certainty associated with younger forests and tropical native dry forests. The low uncertainty for tropical rain and moist forests is due to the relatively large data base for these forest types, whereas for tropical dry forests the data based is small. The other parameter used in the calculations is area planted—it is assumed that this will be well known with an uncertainty of about 5% or less.

Table 1 Key parameters used to estimate the carbon benefits of afforestation / reforestation and an assessment of their uncertainties

Component	Parameter	Uncertainty			Comment
		Low (<20%)	Medium (20-60%)	High (>60%)	
Tropical Native Forests	Biomass accumulation—rain and moist forests	**X** for forests ≥25 yr old	**X** for forests <25 yr old		Chapman Richards using data from an extensive literature review
	Biomass accumulation-dry forest		**X**		
Mangrove Forests	Biomass accumulation	**X** for forests ≥25 yr old	**X** for forests <25 yr old		Literature review of growth rates for mangroves
Plantation Forests	Biomass accumulation		**X**		FAO database

5.1 COMBINING UNCERTAINTIES FOR MULTIPLICATION

The simple error propagation method is based on two equations: one for multiplication and one for addition and subtraction of uncertainties. The equation to be used in case of multiplication is:

$$U_{total} = \sqrt{U_1^2 + U_2^2 + ... + U_n^2}$$

Where:

U_i = percentage uncertainty associated with each of the parameters

U_{total} = the percentage uncertainty in the product of the parameters

An example of combining uncertainties in estimating the carbon benefits from planting native trees in a tropical moist environment using the Tier 1 method is shown below:

	Mean value	Uncertainty (% of mean)
Area planted (ha)	1,000	5
Above and below ground C stock at age 10 yr (t C/ha)	36	45

Thus the carbon emissions are:

1,000 ha *36 t C/ha = 36,000 t C

And the uncertainty = $\sqrt{5^2 + 45^2} \quad = \pm 45\%$

5.2 COMBINING UNCERTAINTIES FOR ADDITION AND SUBTRACTION

In the case of addition and subtraction, for example when carbon emissions are summed up, the following equation will be applied:

$$U_{total} = \frac{\sqrt{(U_1 * x_1)^2 + (U_2 * x_2)^2 ... (U_n * x_n)^2}}{|x_1 + x_2 ... + x_n|}$$

Where:

U_i = percentage uncertainty associated with each of the parameters

x_i = the value of the parameter

U_{total} = the percentage uncertainty in the sum of the parameters

An example of this application is in the combination of carbon stock estimates (addition) shown below:

	Mean	95 % CI
	t (C/ha)	
Living Trees	113	11
Down Dead Wood	18	3
Litter	7	2

Therefore the total stock is 138 t C/ha and the uncertainty =

$$\frac{\sqrt{(11\% * 113)^2 + (3\% * 18)^2 + (2\% * 7)^2}}{|113 + 18 + 7|} = \pm 9\%$$

Using this simple error propagation method is applicable to the calculations used in this AR tool. The Monte Carlo type analysis is more complicated to apply, but gives more reliable results particularly where uncertainties are large, distributions are non-normal, or correlations exist. Furthermore, Tier 2 method can be applied to models or equations, which are not based only on addition, subtraction and multiplication. (The reader is referred to Chapter 5 of IPCC GPG LULUCF for more details on how to implement the Monte Carlo analysis).

6. CALCULATION METHODS

6.1. CHAPMAN-RICHARDS MODEL

The Chapman-Richards function is a widely applied and widely cited growth model. The function is a sigmoid-shaped biological growth model and the field data are used to calibrate it to the growth rate of the forest type. The model itself is simple and is defined on a case-by-case basis by fitting the input data. The model is profoundly sound both statistically and professionally. This growth model was selected because it requires minimum input from the users. Users are required to simply fill in the total area of the A/R project activity and the management effectiveness (more details on the effectiveness rating estimation can be found in the Effectiveness Tool) of the plantation. The effectiveness rating can be overridden with proper justification if desired by the users.

Total Benefit (t CO_2) = (AGC+BGC)

Above-ground Benefit (t CO_2) = Area* (AGC) *(44/12)* Effectiveness

AGC = MAX* [1–EXP(-k* Age)]^[1/(1-m)]

Below-ground Benefit (t CO_2) = Area* ($0.489*AGC^{.890}$) *(44/12)* Effectiveness

Where:

Area	= area of A/R project activity; hectares, ha
AGC	= Above-ground carbon stock, t C ha^{-1}
44/12	= conversion factor from carbon to carbon dioxide equivalent
Effectiveness	= management effectiveness rating (%)
MAX	= asymptote maximum peak biomass yield; tons dry mass per hectare, or t d.m. ha^{-1}
k	= parameter used in modeling tree growth; dimensionless
Age:	= age of forest; years (user-defined)
m	= parameter used in modeling tree growth; dimensionless

Parameters in blue can be entered by the user, while parameters in red have default values under Advanced Inputs, but can be changed by the user. Parameters in black are fixed within the calculations. The age of the forest is optional and can be entered under Advanced Inputs of the Tool, but if not specified by the users, it will default to one year initially. Belowground biomass is estimated using Mokany et al., (2006) root to shoot biomass ratios. Default IPCC conversion factors from biomass to carbon and to carbon dioxide were used.

The data obtained from literature were stratified by forest type (native or commercial plantations – various) and by climate type, and then used with the Chapman-Richards model to develop logistic growth curves. A different growth model was developed for each forest type in its respective climate region.

6.2. TROPICAL NATIVE FORESTS

Three models were developed by climate types (Figures 1, 2 and 3). According to the model used, highest maximum biomass was achieved by forests in the Rain Forest category, followed by forests in the Moist Forest category. Forests in the Dry Forest category had the lowest biomass. Maximum biomass values used to fit curves to data for each category were based on values found by Brown and Lugo (1982) for mature forests. The biomass accumulation curve for forests in the Rain Forest category (Figure 1) approaches a maximum of 370 t C ha^{-1}.

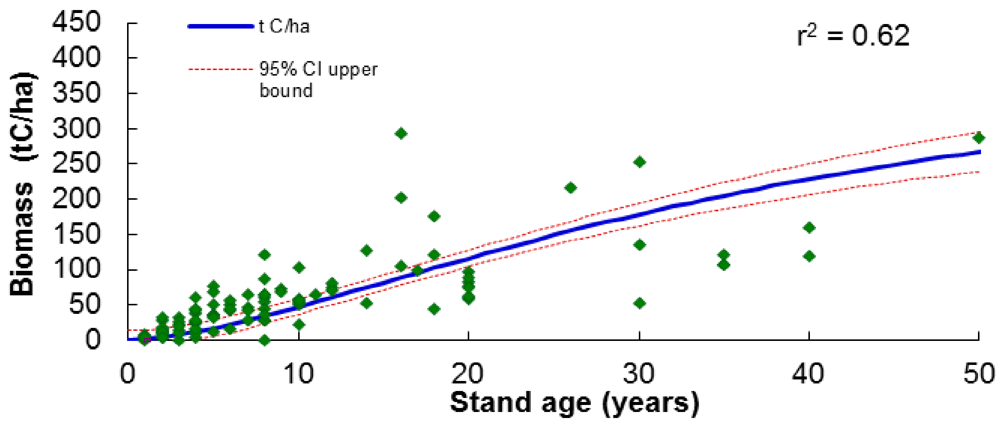

Figure 1: Aboveground biomass accumulation curve for Rain Forest, fitted using 107 data points taken from 20 studies of secondary forest . Upper and lower curves represent upper and lower bounds of 95% CI.

The biomass accumulation curve for forests in the Moist Forest category (Figure 2) approaches a maximum of about 290 t C ha^{-1}, and an R^2 value of 0.50.

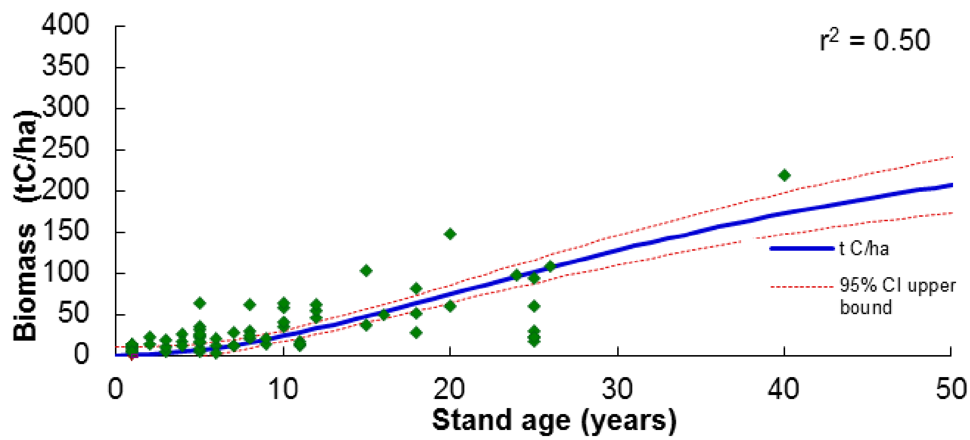

Figure 2: Aboveground biomass accumulation curve for Moist Forest, fitted using 70 data points taken from 9 studies of secondary forest. Upper and lower curves represent upper and lower bounds of 95% CI.

The biomass accumulation curve for forests in the Dry Forests category (Figure 3) approaches a maximum of 90 tC ha-1.

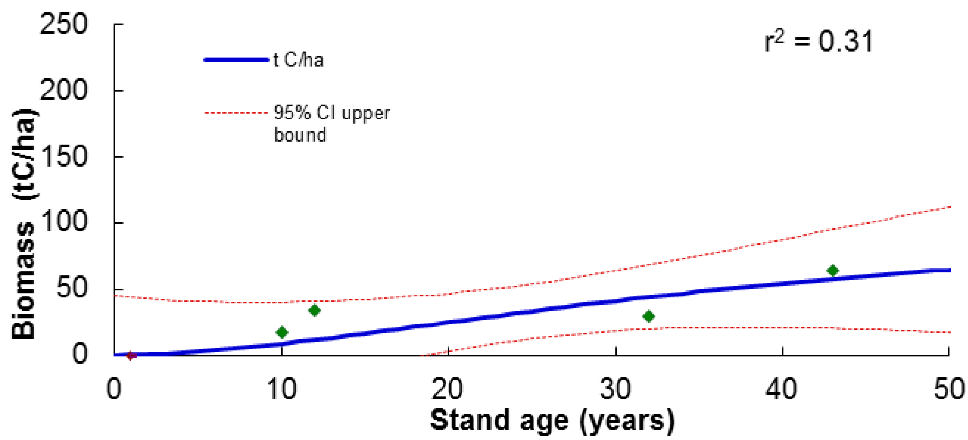

Figure 3: Aboveground biomass accumulation curve for Dry Forest, fitted using four data points taken from two studies of secondary forest. Upper and lower curves represent upper and lower bounds of 95% CI.

Growth parameters developed for each of the three tropical forest types are summarized in Table 2.

Table 2 Literature based growth parameters for estimating biomass accumulation in tropical forests using a Chapman-Richards logistic growth equation.

Forest type	MAX	k	m
Rain Forest	370	0.035	0.40
Moist Forest	290	0.039	0.55
Dry Forest	90	0.037	0.50

Growth parameters for Dry Forest, Moist Forest, and Rain Forest are assigned to each administrative unit based on the dominant FAO ecological zone in which non-forest area is located within the administrative unit (according to a MODIS forest/non-forest land cover map).

6.3. MANGROVE FORESTS

A growth model for secondary mangrove forests was developed using the Chapman-Richards equation applying data from the literature review (data are in Annex 2). The maximum biomass stock is assumed is assumed to be 145 t C ha-1.

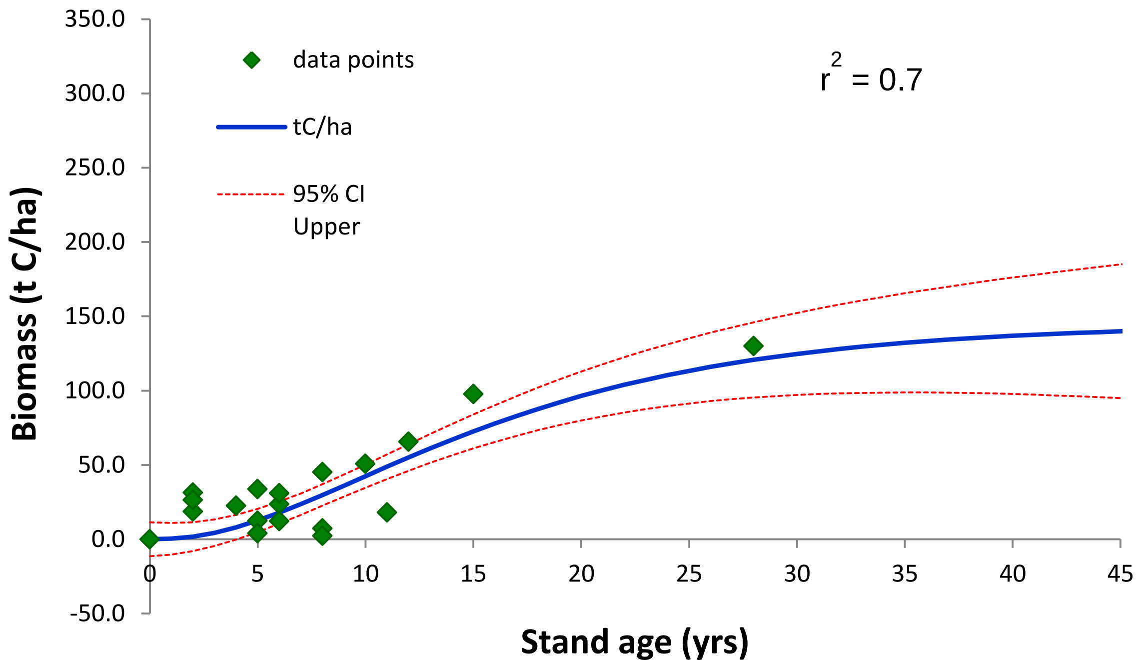

Figure 4: Aboveground biomass accumulation curve for A/R mangrove forest, fitted using 18 data points taken from eight studies of A/R mangroves. Upper and lower curves represent upper and lower bounds of 95% CI.

6.4. PLANTATION FORESTS

Species and climate specific logistic growth models based on the Chapman-Richards equation were developed using the FAO (2005) data and the IPCC (2006) climate zones. First, a climate type was associated to each administrative unit of countries in the AFOLU Carbon Calculator based on the IPCC (2006) climate zones. Then countries recorded in the FAO (2006) database were cross-referenced with countries in the AFOLU Carbon Calculator database, and species listed in such countries were selected and a climate type associated based on the country of occurrence.

The parameters from the FAO database used in modeling biomass carbon accumulation on plantation forests were: mean annual increment (m^3 ha^{-1} yr^{-1}), rotation length (years) and harvest volume (m^3 ha^{-1}). Growth models were developed for each species in each admin unit based on the predominant climate type in that admin unit. Various iterations of the model were ran with the input parameters available per species, and the models that resulted in the greatest fit (greatest r^2) were selected as the best approach for each of the species. The species available for A/R project activities per climate zone along with parameters modeled for estimating carbon accumulation are shown in Table 3.

Table 3 Tree species available in the A/R Tool per climate type and their respective modeled parameters based on the Chapman-Richards equation.

Climate Type	Species	MAX	K	m
Cool temperate	Beech (*Fagus*)	350	0.021	0.63
	Larch (*Larix*)	481	0.024	0.63
	Spruce (*Picea*)	608	0.031	0.63
	Pine all (*Pinus*)	186	0.027	0.63
	Chestnut (*Castanea*)	177	0.072	0.63
	Cunninghamia	222	0.113	0.63
Warm temperate	Pine all (*Pinus*)	251	0.098	0.63
	Slash pine (*Pinus elliotti*)	178	0.101	0.63
	Loblolly pine (*Pinus taeda*)	217	0.101	0.63
	Pinus radiata	368	0.110	0.63
Tropical dry	Acacia all	65	0.158	0.63
	Acacia nilotica	91	0.115	0.63
	Acacia senegal	60	0.092	0.63
	Acacia seyal	85	0.127	0.63
	Ailantus excels	91	0.169	0.63
	Cypress (*Cupressus*)	217	0.063	0.63
	Khaya sp.	83	0.072	0.63
	Teak (*Tectona grandis*)	81	0.063	0.63
	Slash pine (*Pinus elliotti*)	260	0.085	0.63
	Pinus patula	260	0.085	0.63
	Pinus radiata	251	0.080	0.63
Tropical moist/wet	*Agathis sp.*	325	0.101	0.63
	Araucaria angustifolia	356	0.127	0.63
	Gmelina sp.	477	0.127	0.63
	Rubber (*Hevea brasiliensis*)	244	0.169	0.63
	Pine all (*Pinus*)	155	0.195	0.63
	Mahogany (*Swietenia macrophylla*)	207	0.087	0.63
	Teak (*Tectona grandis*)	315	0.056	0.63
	Eucalyptus all	312	0.241	0.63

6.5. HYPOTHETICAL EXAMPLE

To illustrate how this tool works a hypothetical A/R project activity is presented: the project is planting 500 hectares of native forest species in Svay Rieng administration unit in Cambodia. First, users have to select the geographic location of the project, which in this example is in Svay Rieng, Cambodia, an admin unit classified as Moist Tropical Forest.

The tool requires the user to enter the area of the A/R project activity — in this case 500 ha. Then the user has to respond to a simple questionnaire to estimate the effectiveness rating of the A/R project activity. In this example, planting has been completed, but the area has experienced flooding, which caused some minor mortality of seedlings. No human or livestock incursion into the planted areas happened, and the management practices of watering plants and controlling pests have been sufficient to ensure full growth rates, resulting in an estimated effectiveness rating of 90%.

By entering the input parameters above in the equation, we have:

AGC = 290* [1–EXP(-0.039* 1)]^[1/(1-0.55)] = 0.205 t C ha^{-1}

BGC = $0.489*AGC^{0.890}$ = 0.119 t C ha^{-1}

Benefit (t CO_2) = 500* (0.205+0.119)*(44/12)* 0.9

A/R Benefits = **535 t CO_2e**

In this example, the A/R project activity that is 90% effective in planting 500 ha of native forests in Svay Rieng, Cambodia, has resulted in a carbon benefit of approximately **535 t CO_2e** for the first year.

7. OVERRIDING DEFAULT DATA

The ability to override the A/R Tool's default database is very limited. Users may change:

- The type of species planted: from native to mangrove or any of the plantation species according to the climate type in which the A/R project activity is implemented
- The age of the planted forest
- The carbon accumulation rate of the planted forest

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ANNEX I-NATIVE TROPICAL FORESTS

Table 4 Key information on literature about aboveground biomass of secondary tropical forest compiled for developing growth models under the A/R tool. Values reported in literature are rounded to nearest ton here.

Country	Average Annual Precipitation (mm/yr)	Climate Type	Disturbance History	Biomass (t/ha)		Reference
				Min	Max	
India	964	DF	Cleared	-	64	Singh 1975
Uganda	1707	DF	Shifting cultivation	17	34	Omeja et al. 2012
Mexico	900, 1150	MF	Shifting cultivation	11	98	Read and Lawrence 2003
Mexico	900, 1150	MF	Shifting cultivation	8	30	Eaton and Lawrence 2009
Nigeria	1830	MF	Shifting cultivation	3	-	Nye and Greenland 1960
Ghana	1650	MF	Cultivated 30 - 50 yrs	-	219	Greenland and Kowal 1960
Guatemala	1972	MF	Shifting cultivation	4	14	Tergas and Popenoe 1971
India	2200	MF	Shifting cultivation	5	148	Toky and Ramakrishnan 1983
Thailand	1150	MF	Shifting cultivation	5	60	Drew et al. 1978
Thailand	1400	MF	Shifting cultivation	26	63	Sabhasri 1978
Vietnam	1277	MF	Shifting cultivation	4	109	Tran et al. 2010
DRC	2000	RF	Shifting cultivation	11	122	Bartholomew et al. 1953
Brazil	1750	RF	Pasture	1	87	Uhl et al. 1988
Brazil	2290	RF	Cropland	4	176	Alves et al. 1997
Brazil	2500	RF	Slash-and-burn agriculture	50	120	Johnson et al. 2001
Colombia	3000	RF	Cleared and burned not cultivated	19	203	Folster and de las Salas 1976, Folster et al. 1976
Colombia and Venezuela	3500	RF	Slash-and-burn agriculture	44	197	Saldarriaga et al. 1988
French Guiana	2588	RF	Clear cut for	-	33	Maury-Lechon

Country	Average Annual Precipitation (mm/yr)	Climate Type	Disturbance History	Biomass (t/ha) Min	Max	Reference
			logging			1982
Guatemala	2000	RF	Shifting cultivation	8	72	Snedaker 1970
Malaysia	2800	RF	Shifting cultivation	-	99	Kenzo et al. 2010
Malaysia	3577	RF	Shifting cultivation	4	57	Jepsen 2006
Mexico	3640	RF	Cut and cleared, cultivated 1 year	4	44	Williams-Linera 1983
Panama	2000	RF	Shifting cultivation	13	57	Ewel 1971, 1975
Peru	2200	RF	Cropland	9	16	Szott et al. 1994
Venezuela	3520	RF	Shifting cultivation	58	150	Saldarriaga et al. 1986
Venezuela	3520	RF	Shifting cultivation	7	34	Uhl 1987
Brazil	1825	RF	Shifting cultivation	51	136	Salimon and Brown 2000
Brazil	2200	RF	n.a.	16	128	Feldpausch et al. 2004
Costa Rica	5130	RF	Agriculture	29	103	Fonseca et al. 2011
Malaysia	4200	RF	Shifting cultivation	20	50	Ewel et al. 1983
Mexico	4000	RF	Cropland and pasture	23	292	Hughes et al. 1999

RF: Rain Forest; MF: Moist Forest; DF: Dry Forest

ANNEX II--MANGROVES

Table 5 Key information on mangrove biomass literature compiled for developing growth models under the A/R tool.

Authors	Geographic Location	Mangrove Age (yr)	Total Biomass* t C ha^{-1}
Chen et al. (2012)	Shenzhen Bay, Guangdong Province, China	2	31.44
		2	18.74
		2	26.46
Ren et al. (2009)	Leizhou Bay, South China	4	22.51
		5	33.70
		8	45.07
		10	50.81
Liao[a]	Qiongshan, Hainan, China	6	23.63**
		6	12.28**
		11	18.05**
Zan[a]	Futian, Guangdong, China	6	30.88**
Kairo et al. (2009)	Gazi Bay, Kenya	5	12.43**
		8	7.18**
		5	4.11**
		8	2.27**
Kairo et al. (2008)	Gazi Bay, Kenya	12	65.50**
Ong J.E.[b]	Matang, Malaysia	28	130.01**
Christensen B.[b]	Phuket, Thailand	15	97.60**

*The carbon fraction of biomass of 47% was used.

**BGB estimated using average R/S ratio of 0.31 generated from Chen L. et al (2012) and Ren H. et al. (2009) BGB values.

[a] Source of this data is Ren et al. (2009)

[b] Source of this data is Komiyama et al. (2008)

ANNEX III--PLANTATIONS

Table 6 Tree species available per climate zone that can be selected in the A/R tool.

Climate Type	Species
Cool temperate	Beech (*Fagus*) Larch (*Larix*) Spruce (*Picea*) Pine all (*Pinus*) Chestnut (*Castanea*) Cunninghamia
Warm temperate	Pine all (*Pinus*) Slash pine (*Pinus elliotti*) Loblolly pine (*Pinus taeda*) *Pinus radiata*
Tropical dry	Acacia all *Acacia nilotica* *Acacia senegal* *Acacia seyal* *Ailantus excels* Cypress (*Cupressus*) *Khaya sp.* Teak (*Tectona grandis*) Slash pine (*Pinus elliotti*) *Pinus patula* *Pinus radiata*
Tropical moist/wet	*Agathis sp.* *Araucaria angustifolia* *Gmelina sp.* Rubber (*Hevea brasiliensis*) Pine all (*Pinus*) Mahogany (*Swietenia macrophylla*) Teak (*Tectona grandis*) Eucalyptus all