**United States Agency for International Development
Cooperative Agreement No. EEM-A-00-06-00024-00**

Global Climate Change:
Carbon Reporting Initiative

The AFOLU Carbon Calculator

AFOLU CARBON CALCULATOR
THE FOREST MANAGEMENT TOOL: UNDERLYING DATA AND METHODS

Winrock International

AFOLU CARBON CALCULATOR

THE FOREST MANAGEMENT TOOL: UNDERLYING DATA AND METHODS

DISCLAIMER

The author's views expressed in this publication do not necessarily reflect the views of the United States Agency for International Development or the United States Government.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. SCOPE

This document describes the underlying data sources and calculation methods employed in the Forest Management (FM) Tool of the AFOLU Carbon Calculator (http://afolucarbon.org/). The FM Tool is designed for project activities that aim at reducing carbon emissions through changes in forest management and timber harvesting practices.

2. APPLICABILITY

Forest management practices can differ depending on the characteristics of the forest being managed, such as species composition and age. There are basically two forest management practices: uneven-aged, and even-aged forest management. In highly diverse forest stands, such as many managed forests in tropical zones, management practices often target select trees within the forest (i. e. selective logging), thus rendering the age of the remaining forest stands diverse.

Other forests are managed for one or very few species creating homogeneous forest stands with low diversity. This type of management is more typical in temperate climates. In this case, management practices often entail clearcutting of a forest area, with subsequent planting or recruitment of a uniform new cohort of trees.

The FM Tool can account for reduced carbon emissions from improved uneven-aged tropical forest management practices as well as reduced carbon emissions from changes in even-aged forest management practices.

The improved uneven-aged forest management practices that the Tool accounts for are:

1) Reduced impact logging (RIL)
2) Stopping logging (SL), with the assumption that logging will cease to happen.

The improved even-aged forest management practices that the Tool accounts for are:

1) Extended rotation logging (ER)
2) Stopping logging (SL), with the assumption that logging will cease to happen.

3. APPROACH TO THE FM TOOL

3.1 UNEVEN-AGED FOREST MANAGEMENT

The approach employed in the Uneven-Aged FM Tool is based on the methodology described by Pearson et al. (2014)[1], and uses the IPCC's gain-loss approach to calculate the difference in CO_2

---

[1] Timothy R H Pearson et al 2014 *Environ. Res. Lett*. 9 034017. Available at: http://iopscience.iop.org/1748-9326/9/3/034017/

emissions between two scenarios: the pre-project intervention (i.e. conventional logging practices), and the post-project intervention (i.e. stopping or reducing the impact of logging practices). For each scenario, CO_2 emissions are calculated as shown in Box 1, and consist of the sum of emissions from timber extraction, the process of tree felling, and the creation of infrastructure, such as logging roads, skid trails and logging decks (Figure 1).

Box 1: Estimating emissions from conventional selective logging

Emissions (t CO_2e) = [(Timber Tree – Wood Products) + Incidental Damage + Logging Infrastructure Damage]

Note: All terms are expressed in biomass carbon (t CO_2)

(A)   **(B)**   **(C)**

Figure 1. Emissions from selective logging operations in the Forest Management Calculator include: (A) emissions from timber extracted (minus a portion that ends up stored in long-term wood products), (B) emissions from incidental damage to surrounding trees, and (C) emissions from the creation of logging roads, skid trails and landing decks. Photos courtesy of Winrock International.

The approach described by Pearson et al. (2014) employed in the FM tool represents a more complete carbon accounting than the guidance provided by the IPCC (2006) Tier 1 as it includes losses in carbon stocks from incidental damage and logging infrastructure, and permanent storage of carbon in long-term wood products (Winjum et al., 1998).

3.2 EVEN-AGED FOREST MANAGEMENT

Extended rotation benefits arise not from reductions in emissions but through increased sequestered stocks on average over the harvesting cycle both in living biomass and in harvested wood products. Figure 2 demonstrates carbon accumulation and long-term average carbon stocks for a plantation with a 25-year rotation period and a plantation with a 40-year rotation period. The benefit is measured by estimating the difference in long-term average C stocks between the baseline scenario (25-year rotation) and the extended rotation scenario (40-year rotation).
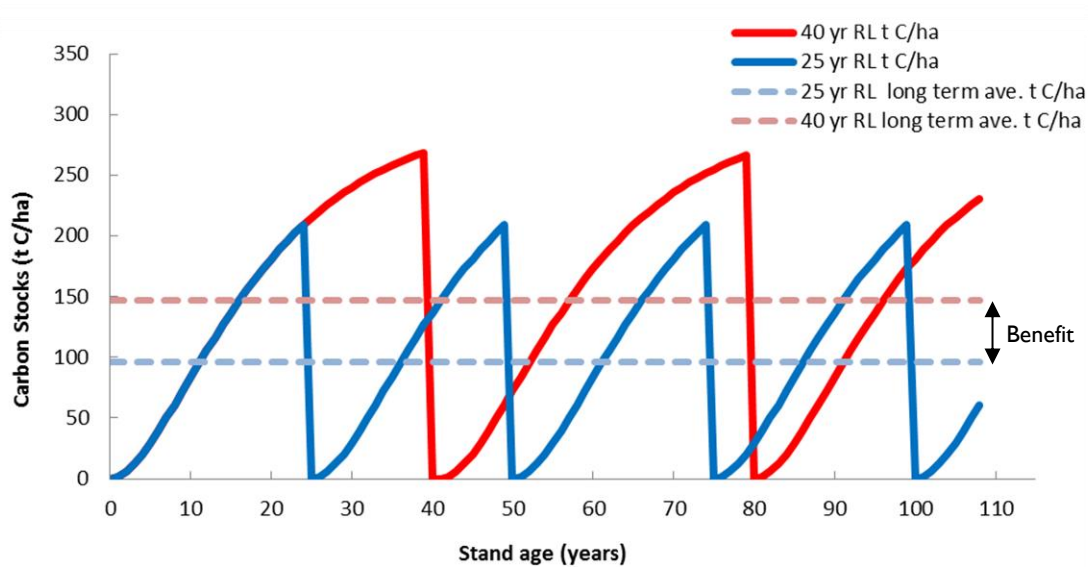
Figure 2 Long term average C stocks in productive forest stands with a 25-year rotation period and a 40-year rotation period

As such, the approach employed in the Even-Aged FM Tool accounts for the long term carbon stock both under business as usual and in the case of project implementation. The carbon stock is projected forward in both live biomass and in harvested wood products to the point where either the actual stock or the average stock is constant. The difference between long term stocks is the benefit from project implementation, as demonstrated in Figure 2.

Box 2: Estimating emissions from even-aged logging

*Emissions (t CO₂e) = Harvest area * Long-term average C stocks in wood products and live trees under even-aged management*

*Benefit long term live biomass extended rotation (t CO₂e) = (Harvest Area * Long-term average C stocks in wood products and live trees under extended rotation even-aged management) – (Harvest area * Long-term average C stocks in wood products and live trees under even-aged management)*

Note: All terms are expressed in biomass carbon (t CO₂)

The approach employed in the Even-Aged FM Tool reflects an improvement from the standard IPCC Tier 1 approach in which biomass carbon accumulation rates are directly correlated to the time since tree establishment (age in years) rather than a constant accumulation rate for the first 20 years, after which the rate declines to a lower constant rate. Instead, the Even-Aged FM 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.

4. DATA SOURCES

4.1. UNEVEN-AGED FOREST MANAGEMENT

ANNUAL HARVEST AREA

The tool calculates the emissions associated with harvesting the annual harvest area which is input by the user. This value is then projected out for another 29 years, so the total avoided emissions over a 30 year period can be estimated.

VOLUME OF TIMBER EXTRACTED BEFORE PROJECT ACTIVITY

Default annual timber extraction rates (m^3 ha^{-1} yr^{-1}) were compiled from the following data sources: FAO (1990), FAO FRA Country Reports (2010)[2], published literature (Holmes et al., 2002; Medjibe et al., 2011; Medjibe and Putz, 2012; Putz et al., 2012), countries' code of forestry practices whenever available (e.g. Guyana and Brazil), consultants (Tropical Forest Foundation [3]), and personal communications (for Bolivia, Brazil, Peru, Democratic Republic of Congo, Republic of Congo, Lao PDR, Vietnam, Cambodia, Thailand, Malaysia, Indonesia, and Papua New Guinea). Users can see what the default data is associated with the administrative region of their project by looking at the "Advanced Inputs" part of the activity page. In some cases no default data was available, so a value of zero is given. Users will have to enter their own data for extraction rates to generate emissions benefits numbers.

EXTRACTED LOG EMISSIONS (ELE) FACTOR

This factor represents the emissions resulting from conversion of the wood in log extracted out of the forest into wood products and the subsequent emissions from retired wood products. In other words, these are the emissions associated with the amount of merchantable wood that is extracted from the forest. Pearson et al., 2014 analyzed data from 13 commercially operated forest concession areas within the tropical moist climate zone of six countries (five concessions in Indonesia, four in Guyana, and one in each of the other four countries) and found a strong correlation ($R2 = 0.99$) between wood density (g cm-1) and ELE (Mg C m-3): ELE =(0.4924 x WD)-0.0158. This relationship is used in the calculation below.

WOOD DENSITY

Values for average volume-weighted wood density of a forest stand in the project area are taken from Reyes et al. (1992). These values are estimated for tropical tree species and vary by continent: 0.57 for Asia, 0.58 for Africa, and 0.60 for Latin America.

---

[2] Available at: http://www.fao.org/forestry/fra/fra2010/en/
[3] More information at: http://www.tropicalforestfoundation.org/

WOOD PRODUCTS

Much of the timber that is extracted from the forest as logs will be emitted to the atmosphere within 100 years of initial timber harvest as wood waste at the mill, or as a result of the oxidation of wood products. However, a small fraction will be effectively sequestered permanently, which is assumed to be any carbon remaining in wood products beyond 100 years. This fraction is calculated based on how much carbon is removed initially as extracted timber (*C_timber*), and varies based on the various wood products class harvested wood is destined to: sawnwood, wood based panels, roundwood, and pulp and paper. The methodology applied in the FM tool follows the approach outlined by Winjum et al (1998) and is described in section 5.1 below.

INCIDENTAL DAMAGE

The logging damage factor reflects the emissions that occur at the location (gap) where the specific tree(s) are felled caused by the decomposition of all the dead wood produced as a result of felling the tree(s). This represents the carbon in the aboveground and belowground biomass of the stump and top of the timber tree felled and left as dead wood in the forest, trees incidentally killed or severely damaged (i.e. uprooted or snapped), and large branches broken off from surviving trees during tree felling. Pearson et al., (2014) fund a strong correlation (R2 = 0.86) between the biomass carbon stock (Mg C ha-1) and the logging damage factor (Mg C m-3) LDF = -0.0039(Carbon Stock) + 1.7817. This relationship is used in the calculation below. The carbon stock data comes from a variety of source and is explained in section 4.2.1 of the Forest Protection Tool Manual.

LOGGING INFRASTRUCTURE

Logging infrastructure emissions include emissions resulting from the creation of logging roads, skid trails and logging decks. Pearson et al., 2014 derived relationships of the carbon emitted per m3 from skids and roads/decks at three sites (Republic of Congo, Indonesia and Guyana. The mean of the three data points were used for each one to derive a skids factor of 0.127 t C m-3 and a roads/decks factor of 0.503 t C m-3.

REDUCED IMPACT LOGGING FACTORS

For RIL projects, CO_2 emissions still occur in the project scenario because timber is still being extracted from the forest, but practices are in place to minimize the negative impact of logging operations on the surrounding forest and soil. Below, the sources of th factors used to adjust the impact of logging operations on emissions are described. In addition, users can alter the volume of timber being extracted in the project scenario.

RIL Incidental Damage Factor: Pinard and Putz (1996) measured carbon stock changes associated with forest harvesting for both conventional and reduced impact logging. Based on data reported in this paper, a factor of 0.723 was applied for the reduced impact of RIL on dead wood stocks produced by the process of tree felling.

RIL Skids Factor: A skid trail factor value of 0.47 was derived by analyzing the studies of Pereira et al. (2002), Holmes et al. (2002) and Pinard et al. (1995), who measured the area of skid trails under RIL and

conventional logging and found RIL area to be 46, 62 and 34% of conventional logging. Averaging these studies gives a reduction of 47% under a RIL scenario.

RIL road and decks factor: A road and decks factor value of 0.65 was derived by analyzing the studies of Pereira et al. (2002) and Holmes et al. (2002), who measured the relative extent of infrastructure under RIL vs. conventional logging.

4.2. EVEN-AGED FOREST MANAGEMENT

The data required by the approach used in the Even-Aged FM Tool were compiled from published literature and global datasets (e.g. FAO FRA). They are described below.

ABOVEGROUND BIOMASS
Data on aboveground biomass (AGB) (t d.m. ha-1) in forest plantations ≥ 20 years and < 20 years was derived from from the IPCC (2006) Guidelines for National Greenhouse Gas Inventories Vol. 4 AFOLU, Table 4.8, 'Above-ground biomass in forest plantations' was then assigned to calculator admin units according to their predefined climatic zone.

BELOWGROUND BIOMASS
The root-to-shoot ratio developed by Mokany et. al (2006)[4] is applied to both default AGB values or user-entered AGB values.

ROTATION LENGTH
Data on growth parameters including rotation lengths (RL) for common commercially planted species globally were sourced from the FAO Global Planted Forests Thematic Study Results and Analysis (2006)[5]. This source listed regional rotation length as a range between the minimum and maximum for tree species, so the mean of the minimum and maximum were applied as the default. Annex 1 contains a table with all rotation lengths used in the calculator.

BIOMASS EXPANSION FACTORS
Biomass expansion factors (BEF) were sourced from IPCC LULUCF (2003) table 3A.1.10 'Default values of biomass expansion factors'.

GROWTH RATE
Data from the FAO Global Planted Forests Thematic Study Results and Analysis (2006) and the IPCC (2006) climate zones were used to develop a set of species and climate-specific logistic growth models

---

[4] Mokany, K, Raison, JR, Prokushkin, A.S. 2006. Critical analysis of root:shoot rations in terrestrial biomes. *Global Change Biology* 12: 84-96.

[5] Del Lungo A., et. al, 2006. Global planted forests thematic study: results and analysis, by Planted Forests and Trees Working Paper 38. FAO. Rome. Available at www.fao.org/forestry/site/10368/en.

using the Chapman-Richards equation[6]. The Chapman-Richards function is a widely applied and cited growth model that captures the non-linear pattern of forest growth -- typically slow carbon accumulation at earlier ages, increasing as the forests mature, and peaking and tapering off when a mature age is reached. The function is a sigmoid-shaped biological growth model and 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.

Parameters from the FAO database used in modeling biomass carbon accumulation on plantation forests were: mean annual increment (m³ ha⁻¹ yr⁻¹), rotation length (years) and harvest volume (m³ ha⁻¹).

Regional default conifer and broadleaf growth rates (applied where only Required Inputs are provided by user in the FM Tool) were assigned based on information published in the FAO Global Planted Forests Thematic Study Results and Analysis (2006)[7] on region-specific information on dominant productive species (Table 12: Main species established for productive purposes in plantation forests and semi-natural forests). See Annex II for a list of selected default conifer and broadleaf species and the countries they are applied to.

Under Advanced Inputs, users can select from a list of species for which growth curves were developed (Chapman-Richards function).   These are listed in Table 1.

Table 1: Tree species available in the Even-Aged FM 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

---

[6] The same species and climate-specific growth equations developed for the AFOLU Carbon Calculator Afforestation/Reforestation Tool (A/R Tool) were applied for estimating growth in even-aged forest stocks for the FM tool.

[7] Del Lungo A., et. al., 2006. Global planted forests thematic study: results and analysis, by Planted Forests and Trees Working Paper 38. FAO. Rome. Available at: www.fao.org/forestry/site/10368/en.

	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

MILL CONVERSION EFFICIENCY

The mill conversion efficiency default is set at 50% but users may alter this value if desired.

HALF-LIFE OF LONG-TERM PRODUCTS

Defaults for the half-life of long-term wood products were sourced from Skog,

et. al (2000)[8].   The half-life of furniture (30 years) will be the main default, but users are be able to select other forest products for which half-life data are available from a dropdown menu, as detailed in the table below.

Table 2 Long-term wood products and half-life (Skog et. al, 2000)

PRODUCT	Half Life (years)
Single Family Homes	100
Multi Family Homes	70
Mobile Homes	20
Non Residential Construction	67
Pallets	6
Manufacturing	12
Furniture	30
Railroad Ties	30
Paper (free sheet – i.e. long lived publications)	6
Paper (all other)	1

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

---

[8] Skog, K.E., Nicholson, G.A., 2000. Carbon Sequestration in Wood and Paper Products. USDA Forest Service Gen. Tech. Rep. RMRS-GTR-59, Chapter 5.

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 3).   A brief primer of the steps involved in assessing total uncertainties for each carbon benefit estimate is provided with some 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 deforestation rate and carbon stocks, 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.

Table 3: Key parameters used to estimate the carbon benefits for forest management and an assessment of their uncertainties.   Where no comment is provided, the uncertainty was estimated based on expert opinion.

Component	Parameter	Uncertainty			Comment
		Low (<20%)	Medium (20-60%)	High (>60%)	
Uneven-Aged Forest Management	Annual harvest area				Input by user
	Volume of timber extracted before project activity		For areas where a default value was available	For areas where no defaults exist	
	Extracted log emissions factor	X			Based on strong correlation with wood density
	Wood density	X			Based primarily on commercial species
	Wood products		X		
	Incidental Damage	X			Based on strong correlation (R2 = 0.86) with carbon stocks
	Carbon stocks				SEE FOREST PROTECTION TOOL
	Logging Infrastructure		X		Based on mean of values from three different countries.
	RIL incidental damage factor		X		Based on studies in limited areas
	RIL skids factor		X		Average of three studies
	RIL road and decks factor		X		Based on studies in limited areas
Even-Aged Forest Management	Above-ground biomass		X		IPCC defaults
	Below-ground biomass	X			Based on published paper
	Rotation length			X	Mean of global min and max
	Biomass expansion factors		X		IPCC defaults
	Growth rate		X		Chapman Richards
	Mill conversion efficiency		X		50% default –
	Half-life of long-term products		X		Based on published paper

From the table above, the uncertainty of the carbon benefit estimates generated using the FM Tool are likely to be medium, given the input parameters employed in the calculations are of medium uncertainty. Users can strive for lowering the uncertainty associated with carbon benefits estimated using the FM Tool by overriding the defaults values provided with inputs with a greater certainty than presented in Table 3.

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. 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

As an example of combining uncertainty in carbon emissions from volume of timber extracted using the Tier 1 method:

	Mean value	Uncertainty (% of mean)
Area harvested (ha)	1000	5
Volume extracted (m³/ha)	12	20
Extracted log emission factor (t C/m³)	0.28	15

Thus the carbon emissions are:

1,000 ha *12 m3/ha *0.28 t C/m3 = 3,360 t C

And the uncertainty = $\sqrt{5^2 + 20^2 + 15^2} = \pm 25\%$

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 emissions from each component of the logging operation—from the felled tree, the incidental damage, and the logging infrastructure (addition):

Component	Mean emission (t C)	Uncertainty (% of mean)
Felled tree	1,710	25
Incidental damage	5,250	15
Logging infrastructure	7,450	30

The total emissions are 14,410 t C and the uncertainty =

$$\frac{\sqrt{(25\% * 1710)^2 + (15\% * 5250)^2 + (30\% * 7450)^2}}{|1710 + 5250 + 7450|} = \pm 17\%$$

In this case the total uncertainty is lower than either of that of the components and is weighted by the relative magnitude of each emission source.

Using this simple error propagation method is applicable to many of the calculations used in this FM tool, but as the reader is aware, for some of the calculations given in the next section, the number of parameters and steps involved is quite complex and a more advanced. The Monte Carlo type analysis would be needed. It 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

Parameters in blue must be specified by the user under Required Inputs. Parameters in red have default values under Advanced Inputs, but can be changed by the user. Parameters in **black** are fixed within the calculations.

6.1 UNEVEN-AGED FOREST MANAGEMENT

STOP LOGGING

For project activities that stop logging, there are no emissions associated with the project scenario because timber is no longer being extracted from the forest. Therefore, the CO_2 benefit of stopping logging activities is equal to the emissions associated with conventional logging activities that are no longer occurring.

$$Benefits_{Stop\_Logging} \text{ (t } CO_2e) = Emissions_{Conv} \hspace{3cm} (1)$$

The methods for estimating emissions from selective logging use the IPCC (2003) gain-loss approach for carbon accounting, and are based on the approach described by Pearson et al. (2014)[9]. Equation 2 is used to calculate emissions from logging prior to project intervention using conventional practices. It is a function of: (i) the area logged in a given year; (ii) the amount of timber extracted per unit area per year; (iii) the amount of dead wood produced in a given year from tops and stump of the harvested tree, mortality of the surrounding trees caused by the logging, and tree mortality from the skid trails, roads, and logging decks, and (iv) the biomass that went into long term storage as wood products.

$$Emissions_{conv} = [(TimberTree_{before} - Wood\ Products_{before}) + Incidental\ Damage_{conv} + Logging\ Infrastructure_{conv}] \times 44/12 \hspace{0.5cm} (2)$$

Note: Following a logging event, the opening of the canopy will lead to increased light penetration and decreased competition for water and nutrients. This could lead to higher sequestration rates in these areas than would occur in the absence of harvest. However, the incremental gains of the smaller trees may not offset the gains that were being made by the larger tree that was removed. The literature available on the subject does not present consistent conclusions, yet any elevation in sequestration rates appears to be minimal, and regrowth takes many decades -- longer than the 30-year re-entry cycle of many tropical timber-harvesting operations (see Pearson et al. 2014 for a more in-depth discussion). Given the uncertainty and lack of empirical data, regrowth or suppressed sequestration in or around the logging gap is not considered in these calculations.

REDUCED IMPACT LOGGING ACTIVITIES

The benefit of RIL activities is equal to the difference between emissions associated with conventional logging activities and emissions associated with RIL activities:

$$Benefits_{RIL} \text{ (t } CO_2e) = Emissions_{Conv} - Emissions_{RIL} \hspace{3cm} (3)$$

Emissions associated with reduced impact logging are also calculated using the same equations outlined above, but apply adjustment factors to account for the minimized impact of RIL operations on forest carbon stocks.

$$Emissions_{RIL} = [(TimberTree_{after} - Wood\ Products_{after}) + Incidental\ Damage_{RIL} + Logging\ Infrastructure_{RIL}] \times 44/12 \hspace{0.5cm} (4)$$

CONVENTIONAL LOGGING EMISSIONS CALCULATIONS

The equations below show how the components of equation 2, emissions from conventional logging, are calculated.

Conventional - Carbon Emissions from Volume of Timber Extracted

$$TimberTree_{before} = AHA \times VolExt\_before \times ELE$$

---

[9] Pearson TRH, S. Brown, and F. Casarim. (2014). Carbon emissions from tropical forest degradation caused by logging. *Environmental Research Letters*, 9

ELE = (0.4924 x WD)-0.0158

Where:

TimberTree = carbon in extracted timber (t C)
AHA = annual harvest area (ha)
VolExt_before = volume timber over bark extracted before project intervention (m³ ha⁻¹)
ELE = Extracted Log Emissions (t C m⁻³ extracted)
WD = Wood Density (t m⁻³)

The equation to calculate timber emissions is based on the volume of timber extracted per hectare before the implementation of the project activity took place (*VolExt_before*) and the annual harvest area (AHA). Default values for both factors are provided, but can be changed if desired. Multiplying the volume of timber extracted per hectare by area harvested yields the total volume of timber extracted from the forest, which is then converted to carbon using the extracted log emissions factor.

Users can adjust the wood density value under advanced inputs. This will also impact the calculation under RIL.

Conventional - Carbon Stored in Long Term Wood Products

$$WoodProducts = \sum_{class=1}^{4} C\_timber_{class} - C\_ww_{class} - C\_slp_{class} - C\_addlox_{class}$$

Where:

WoodProducts = carbon permanently stored in long term wood products (t C)
C_timberclass = carbon in timber extracted from project area that ends up in a given product class
C_wwclass = carbon in a given product class that ends up as wood waste
C_slpclass= carbon in a given product class that is oxidized in less than 5 years
C_addloxclass = carbon in a given product class that is oxidized between 5-100 years

Step 1. Proportion of total carbon extracted that resides in each wood product class. Wood products are classified into one of four categories commonly reported to the Food and Agriculture Organization (FAO): sawnwood, woodbase panels, other industrial roundwood, and paper and paperboard. Because these wood product classes have different lifecycles, it is necessary to divide the total timber extracted from the project area into these four product classes. For each country included in the FM tool, production volumes of sawnwood, wood-base panels, and other industrial roundwood were obtained from FAO databases for the year 2008 and converted to carbon using volume to biomass conversion factors from Table 1 of Winjum et al. (1998) and a carbon conversion factor of 0.47 (1 t biomass = 0.47 t C). (The paper and paperboard class is reported in units of biomass, therefore no conversion from volume was needed.) After all product classes were represented in a consistent unit

(carbon), proportions of the total carbon in each product class could be derived for each country. The assumption was that the proportions of extracted timber in the project area going into each product class were equal to the proportions for the country in which the project is located.

Step 2: Carbon in wood waste. The proportion of carbon in each wood product class that is oxidized immediately at the mill as wood waste during the production of commodities (C_ww) is assumed to be equal to 24% for developing countries (Winjum et al., 1998).

Carbon emitted due to wood waste is therefore equal to:

$C\_ww = C\_timber \; x \; 0.24$.

Step 3: Carbon in short-lived products. Winjum et al. (1998) give the following proportions of each product class that are oxidized in the short-term (<5 yr):

Sawnwood	0.2
Woodbase panels	0.1
Other industrial roundwood	0.3
Paper and paperboard	0.4

Carbon emitted due to short-term oxidation of wood products in each class are:

$C\_slp = (C\_timber – C\_ww) * proportion \; oxidized \; in \; <5yr$

Step 4: Carbon in additional oxidized fraction. Winjum et al. (1998) gives annual oxidation fractions for each class of wood products split by forest region (boreal, temperate, tropical). In the calculator, these fractions have been projected over 95 years to give the additional proportion that is oxidized between the 5th and 100th years after initial harvest. For this calculation, all administrative units in the tool were assumed to be in the tropical forest region.

Sawnwood	0.84
Woodbase panels	0.97
Other industrial roundwood	0.99
Paper and paperboard	0.99

Emissions associated with the additional oxidation in each class are:

$C\_addlox = (C\_timber – C\_ww – C\_slp) \; x \; proportion \; oxidized \; 5\text{-}100 \; yr$

Conventional - Carbon Emissions from Incidental Damage

$IncidentalDamage_{conv} = LDF \; x \; VolExt\_before$

$LDF = -0.0039 \; (TreeCarbonStock) + 1.7817$

Where:

LDF = Logging Damage Factor, the carbon emitted due to damage to surrounding trees per m³ of timber extracted.

TreeCarbonStock = The carbon stored in the trees (above and below ground) (t C ha⁻¹).

Users can adjust the Tree Carbon Stock value under advanced inputs, which will also impact the RIL calculations.

Conventional - Carbon Emissions from Logging Infrastructure

LoggingInfrastructure$_{conv}$ = Skids$_{conv}$ + RoadsDecks$_{conv}$

Skids$_{conv}$ = SkidsFactor x AHA x VolExt_before

RoadsDecks$_{conv}$ = RoadsDecksFactor x AHA x VolExt_before

Where:

LoggingInfrastructure$_{conv}$ = The carbon emitted due to logging infrastructure in conventional logging (t C ha⁻¹)

Skids$_{conv}$= The carbon emitted due skids in conventional logging (t C ha⁻¹)

RoadsDecks$_{conv}$ = Carbon emitted due to roads/decks in conventional logging (t C ha⁻¹)

SkidsFactor = 0.127 (t C m⁻³)

RoadsDecksFactor = 0.503 (t C m⁻³)

Due to the open structure of tropical dry forests, trees do not need to be cleared to create logging infrastructure in these forests, and therefore, carbon emissions from logging infrastructure are assumed to be zero in administrative units dominated by dry forests.

REDUCED IMPACT LOGGING EMISSIONS CALCULATIONS

The equations below show how the components of equation 4, emissions from reduced impact logging, are calculated.

RIL - Carbon Emissions from Volume of Timber Extracted

The equation to calculate timber emissions in the RIL scenario is based on the volume of timber extracted per hectare AFTER the project activity took place (*VolExt_after*). A default value is provided is users opt to only enter data under Required Inputs (the default assumes that the quantity of timber extracted in RIL is the same as for conventional logging), but the user has the option to change this value under Advanced Inputs.

TimberTree$_{after}$ (t C) = AHA x VolExt_after x ELE

ELE = =(0.4924 x WD)-0.0158

Where:

TimberTree = carbon in extracted timber (t C)
AHA = annual harvest area (ha)
VolExt_after = volume timber over bark extracted after project intervention (m³ ha⁻¹)
ELE= Extracted Log Emissions (t C m⁻³ extracted)
WD= Wood Density (t m⁻³)

RIL - Carbon Stored in Long Term Wood Products

The same 3-step methodology proposed by Winjum et al. (1998) and described in Stop Logging Activities above is followed for calculating the carbon stored in long-term wood products in the RIL scenario, but the calculations to derive WoodProducts$_{after}$ are based on the volume extracted in the project scenario, VolExt_after.

RIL - Carbon Emissions from Incidental Damage

IncidentalDamage$_{conv}$ = LDF x VolExt_after x RIL_DamageFactor

LDF = -0.0039x(TreeCarbonStock) + 1.7817

Where:

LDF = Logging Damage Factor, the carbon emitted due to damage to surrounding trees per m³ of timber extracted.

TreeCarbonStock = The carbon stored in the trees (above and below ground) (t C ha⁻¹).

RIL Damage factor = 0.723

The same methodology as cited above in Stop Logging section is followed, but in the project case the resulting estimates are multiplied by 0.723 to account for the reduced damage caused to the surrounding forest as a result of better logging practices.

RIL - Carbon Emissions from Logging Infrastructure

LoggingInfrastructure$_{RIL}$ = Skids$_{RIL}$ + RoadsDecks$_{RIL}$

Skids$_{RIL}$ = SkidsFactor x AHA x VolExt_before x RIL_SkidsFactor

RoadsDecks$_{RIL}$ = RoadsDecksFactor x AHA x VolExt_before x RIL_RoadsDecksFactor

Where:

LoggingInfrastructure$_{conv}$ = The carbon emitted due to logging infrastructure in conventional logging. (t C ha^{-1})

Skids$_{conv}$= The carbon emitted due skids in conventional logging. (t C ha^{-1})

RoadsDecks$_{conv}$= The carbon emitted due to roads and decks in conventional logging. (t C ha^{-1})

SkidsFactor:= 0.127 (t C m^{-3})

RoadsDecksFactor:= 0.503 (t C m^{-3})

RIL_SkidsFactor= 0.47

RIL_RoadsDecksFactor = 0.65

Carbon emissions from logging infrastructure are calculated in the RIL scenario in the same way cited above, except that the resulting estimates are multiplied by 0.47 and 0.65 to account for the reduced damaged caused by skid trails and logging roads/decks respectively in a RIL scenario. Dry forests are also assumed to have no emissions associated with infrastructure, given their openness of understory.

Under advanced inputs, users may input their own proportion reduction for skid trails and logging roads/decks to override the FM Tool's default values.

HYPOTHETICAL EXAMPLE

A hypothetical uneven-aged FM project activity is undertaking reduced impact logging on 10,000 hectares of native forests in the Loreto province in Peru. While the total area under management is 10,000 ha, the FM Tool automatically calculates[10] the <u>annual</u> harvest area to be 333 ha, based on the average rotation length of 30 years in forest concessions in the tropics.

AHA = THA / RL

Where:
THA (total harvest area) = 10,000 ha
RL (rotation length) = 30 years

Thus, equating to:
AHA (annual harvest area) = 10,000 / 30
AHA (annual harvest area) = 333.33 ha/yr

---

[10] If annual harvest area is known, it can be entered under 'Advanced Inputs' in the FM Tool, overriding the automatic calculation.

The type of forest management is reduced impact logging (RIL) in this example, with reduction of the extraction rate after the project activity intervention from 8m^3 ha^{-1} yr^{-1} to 5m^3 ha^{-1} yr^{-1}.

Benefits (t CO$_2$e) = (Emissions from Conventional Logging) – (Emissions from RIL)

Benefits (t CO$_2$e) = (AHA x {[(Vol$_{Conv}$ x WD x CF) -WoodProducts$_{Conv}$] + (Vol$_{Conv}$ x DamageFactor$_{Conv-LA}$) + (Vol$_{Conv}$ x LoggingInfrastructure$_{Conv}$)} x (44/12)) - (AHA x {[(Vol$_{RIL}$ x WD x CF) - WoodProducts$_{RIL}$] + (Vol$_{RIL}$ x DamageFactor$_{RIL-LA}$) + (Vol$_{RIL}$ x LoggingInfrastructure$_{RIL}$)} x (44/12))

Where:
AHA = 333.33 ha
Vol$_{Conv}$ = 8 m^3 ha^{-1}
Vol$_{RIL}$ = 5 m^3 ha^{-1}
WD = 0.6 t m^{-3}
WoodProducts$_{Conv}$ = 0.154 t C
WoodProducts$_{Conv}$ = 0.096 t C
DamageFactor$_{Conv-LA}$ = 1.047 t C m^{-3} (for Latin America)
DamageFactor$_{RIL-LA}$ = 1.047*0.723 = 0.757 t C m^{-3} (for Latin America)
LoggingInfrastructure$_{Conv}$ = 0.6 t C m^{-3}
LoggingInfrastructure$_{RIL}$ = 0.503*0.65 = 0.327 t C m^{-3}
CF = 0.47 (IPCC, 2006)
44/12 = conversion factor from carbon to carbon dioxide equivalent

Thus, benefits equate to:

Benefits (t CO$_2$e) = (333.33 x {[(8 x 0.6 x 0.47) -0.154] + (8 x 1.047) + [(8 x 0.127) + (8 x 0.6)]} x (44/12)) – (333.33 x {[(5 x 0.6 x 0.47) -0.096] + (5 x 1.047 x 0.723) + [(5 x 0.127 x 0.47) + (5 x 0.503 x 0.65)]} x (44/12))

Benefits (t CO$_2$e) = 9,688

Thus, in this hypothetical example, the FM project activity that harvests a little over 333 ha of native forests annually (10,000 ha managed over a 30 years) in Loreto, Peru, resulted in a carbon benefit of approximately **9,688 t CO$_2$e** for the focal year.

6.2 EVEN-AGED FOREST MANAGEMENT

EXTENDED ROTATION
The methods for estimating emissions from extending the rotation (ER) of managed forests are calculated as the mean aboveground forest biomass at baseline harvest (AGB) plus the number of extra years growth (ERY) to the new rotation age multiplied by an annual growth rate (GR) multiplied by a root-shoot ratio (RS).

➢ Baseline live biomass

Under Required Inputs, default aboveground biomass values are based on the following user inputs: (a) whether the managed area consists of mainly conifer or broadleaf species and (b) the age of the stand (<20 years or ≥ 20 years). Under Advanced Inputs, users have the option of entering site-specific AGB or the total the baseline live biomass (BL).

$$BL = AGB * (1 + RS)$$

Where:

BL = Baseline live biomass

AGB = Aboveground biomass

RS = Root-to-shoot ratio

➢ Extended rotation live biomass

$$ERB = (AGB + (ERY * GR)) * (1 + RS)$$

$$ERY = ERL - RL$$

Where:

ERB = Extended rotation live biomass

AGB = Aboveground biomass

ERY = Extended rotation years

GR= Growth rate

RS = Root-to-shoot ratio

ERL = Number of years in extended rotation harvest cycle

RL = Number of years in baseline harvest cycle (rotation length)

➢ The long term live tree biomass

Equals the total biomass divided by the number of years in the rotation (RL or ERL).

$$LTB = BL / 2$$

$$LTERB = ERB / 2$$

Where:

LTB = Long term baseline

LTERB = Long term live biomass extended rotation

➢ <u>Wood products at time zero baseline</u>

The initial post-harvest wood product biomass is equal to the AGB divided by the biomass expansion factor (BEF) and multiplied by the milling conversion efficiency (ConvEff).

$$WPBL_0 = AGB / BEF * ConvEff$$

Where:

$WPBL_0$ = Wood products at time zero baseline

➢ <u>Wood products at time zero extended rotation</u>
$$WPER_0 = (AGB + (ERY * GR)) / BEF * ConvEff$$

Where:

$WPER_0$ = Wood products at time zero extended rotation

AGB = Aboveground biomass

RS = Root-to-shoot ratio

GR = Growth rate

BEF = Biomass expansion factor

ConvEff = Conversion efficiency

➢ <u>Wood products at time t baseline</u>

At any point in time post-harvest the current wood product stock will be calculated using a decay curve based on the half-life (1/2 life) of the products produced.

Wood products at time t baseline = $(EXP(-((-(((LN(0.5))/½ \ life)) * t)))) * WPBL_0$

Where:

$WPBL_0$ = Wood products at time zero baseline

1/2 life = Half-life of wood products

➢ <u>Wood products at time *t* baseline extended rotation</u>

Wood products at time t extended rotation = (EXP(-((-((LN(0.5))/ ½ life)) * t)))) * WPER$_0$

Where:

WPER$_0$ = Wood products at time zero extended rotation

½ life = Half-life of wood products

➢ <u>Long term average stock</u>

To calculate the long term average stock it is necessary to model out multiple harvests to the point where the retirement of wood products is equal to the inputs from new harvests.

Run for *t = 1* to *t = 600*

Include second harvest at rotation length +1, third at rotation length *2 +1, Fourth at rotation length * 3 + 1 …. Twentieth at rotation length * 19 +1

Sum across harvests and take average stock for final "rotation length" years. (Long-term wood product baseline (LTWPB) and long-term wood product extended rotation (LTWPER)

➢ <u>Benefit:</u>

The benefit of extended rotation is equal to the area (Area) multiplied by the long term average stocks in wood products and live trees under extended rotation, minus the long term average stocks in wood products and live trees in the baseline case.

Benefit long term live biomass extended rotation (t CO2) = [(LTERB * Area) - (LTB * Area)] * (44/12) * Effectiveness

Where:

LTERB = Long-term extended rotation biomass

LTB = Long-term biomass

44/12 = conversion factor from carbon to carbon dioxide equivalent

Benefit wood products extended rotation (t CO2) = [(LTWPER * Area) – (LTWPB * Area)] * (44/12) * Effectiveness

Where:

LTWPER = Long-term wood product extended rotation

LTWPB = Long-term wood product biomass

44/12 = conversion factor from carbon to carbon dioxide equivalent

Total benefits *(t CO2) = (Benefit long term live biomass extended rotation + Benefit wood products extended rotation)*

STOP LOGGING

Stop logging benefits arise from increased sequestered stocks in a system with no harvest relative to the long term average stock under timber harvest including ongoing storage in harvested wood products.

➢ Baseline live biomass

$$BL = AGB * (1 + RS)$$

Where:

AGB = Aboveground biomass

RS = Root-to-shoot ratio

➢ Long term baseline

The long term live tree biomass (LTB) is equal to the total biomass (BL) divided by the number of years in the rotation (RL).

$$LTB = BL / 2$$

Where:

LTB = Long term live tree biomass

BL = Baseline live biomass

➢ Wood products at time zero baseline

The initial post-harvest wood product biomass is equal to the aboveground biomass (AGB) divided by the biomass expansion factor (BEF) and multiplied by the milling conversion efficiency (ConvEff).

$$WPBL_0 = AGB / BEF * ConvEff$$

Where:

$WPBL_0$ = Wood products at time zero baseline

BEF = Biomass expansion factor

ConvEff = Conversion efficiency

➢ Wood products at time *t* baseline

At any point in time post-harvest, the baseline wood product stock will be calculated using a decay curve based on the half-life of the products produced.

*Wood products at time t baseline = (EXP(-((-((LN(0.5))/ ½ life)) * t)))) * WPBL$_0$*

Where:

½ life = The half-life of wood products (default is furniture, 30 years)

WPBL$_0$ = Wood products at time zero baseline

➢ Long term average stock

To calculate the long term average stock it is necessary to model out multiple harvests to the point where the retirement of wood products is equal to the inputs from new harvests.

   Run for *t = 1* to *t = 600*

   Include second harvest at rotation length +1, third at rotation length *2 +1, Fourth at rotation length * 3 + 1 …. Twentieth at rotation length * 19 +1

   Sum across harvests and take average stock for final "rotation length" years. (LTWPB)

➢ Long-term project stock

The project would involve taking the mean stock in the timber harvest areas and continuing forest growth (GR) to and beyond timber harvest age.

   $P = (AGB / 2 + (50 * GR)) * (1+RS)$

P =Total long term project stock

AGB = Aboveground biomass

GR = Growth rate ((MAX(1–EXP(-k*age))^(1/1-m))*

RS = root-to-shoot ratio

50 = A simplifying assumption that fifty years additional growth (GR) is immediately credited to the midpoint of the timber harvest cycle (AGB/2).

➤ <u>Benefit:</u>

Benefit long term live biomass stop logging (t CO2) = (P * Area) - ((LTB + LTWPB) * Area) * 44/12 * Effectiveness

Where:

P = Total long term project stock

LTB = Long-term baseline

LTWPBL = Wood product baseline

44/12 = conversion factor from carbon to carbon dioxide equivalent

HYPOTHETICAL EXAMPLE

A hypothetical even-aged FM project activity intends to extend the rotation of a 1000 hectare tree plantation comprised of broadleaved species in the Kakheti region of Georgia. The total area under forest management is 1000 ha and the dominant class of species in this example, is broadleaved species. The age of the plantation in this example is 25 years.

Using the FM Tool's default data, the baseline live biomass is calculated to be 129.5 t d.m. ha-1:

$$BL = AGB * (1+RS)$$

Where:

AGB (Aboveground biomass) = 100

RS (Root-to-shoot ratio) = $0.489*100^{0.89}$

Thus, equating to:

BL (Baseline) = 100 + (1+ 0.292)
              = 129.5

The calculator also automatically calculates the biomass in the stand under the extended rotation period scenario using a default extended rotation period of 5 years and a growth rate developed using the Chapman Richards function.

$$ERB = (AGB + (ERY * GR)) * (1 + RS)$$

$$ERY = ERL - RL$$

Where:

AGB (Aboveground biomass) =129.5

ERY (Extended rotation years) = 5

GR (Growth rate) **=** *(MAX*(1−EXP(-k*56))^(1/1-m))*

ERL (Length of extended rotation) = 56

RL (Baseline rotation length) = 51

Thus equating to:

ERB (Extended rotation biomass) = (100+(5*(1−EXP(-0.024*56))^(1/1-0.63)))*(1+0.292)

$$= 154.3$$

Next the calculator determines what the long term baseline live tree biomass and the long term live tree extended rotation biomass.

> $LTB = BL / 2$

> $LTERB = ERB / 2$

Where:

BL (Baseline) = 129.5

ERB (Extended rotation baseline) = 154.3

Thus equating to:

LTB (Long-term baseline) = 64.7

LTERB (Long-term extended rotation baseline) = 77.2

Then, the post-harvest wood product biomass under the baseline scenario and the project scenario is calculated using a default 50% conversion efficiency and default biomass expansion factor for broadleaf species in temperate climates.

> $WPBL_0 = AGB / BEF * ConvEff$

Where:

AGB (Aboveground biomass) =129.5

BEF (Biomass expansion factor) = 1.4

ConvEff (Conversion efficiency) = 0.5

WPBL$_0$ (Wood products at time zero baseline) = 30.3

$$WPER_0 = (AGB + (ERY * GR)) / BEF * ConvEff$$

Where:

AGB (Aboveground biomass) =129.5

BEF (Biomass expansion factor) = 1.4

ERY (Extended rotation years) = 5

GR (Growth Rate) = 1–EXP(-0.024*56))^(1/1-0.63))

BEF (Biomass expansion factor) = 1.4

ConvEff (Conversion efficiency) = 0.5

WPER$_0$ (Wood product extended rotation) = 44.6

Then, using a decay curve based on default data on the half-life of wood products (default is furniture-30), the wood products at any given time in the baseline scenario as well as the extended rotation scenario are calculated as:

$$WPBL_t = (EXP(-((-(((LN(0.5))/ ½ \ life)) * t)))) * WPBL_0$$

Where:

WPBL$_0$ (Wood products at time zero baseline) = 30.3

1/2 life = 30

WPBL$_t$ (Wood Products at time t baseline)

$$WPER_t = (EXP(-((-(((LN(0.5))/1/2 \ life)) * t)))) * WPER_0$$

Where:

WPER$_0$ (Wood products at time zero extended rotation) = 44.6

1/2 life = 30

WPER$_t$ (Wood products at time t extended rotation)

Next, the long term average stock is modeled out over multiple harvests to the point where the retirement of wood products is equal to the inputs from new harvests.

Finally, the benefit is calculated as the area multiplied by the long term average stocks in wood products and live trees under extended rotation, minus the long term average stocks in wood products and live trees in the baseline case.

*Benefit long term live biomass extended rotation (t CO2) = [(LTERB * Area) - (LTB * Area)] * (44/12) * Effectiveness*

*Benefit long term live biomass extended rotation (t CO2) = [(77.2 * 1000) - (64.7 * 1000)] * (44/12) * 1]*
$$= 45,601.9$$

*Benefit wood products extended rotation (t CO2) = [(LTWPER * Area) – (LTWPB * Area)] * (44/12) * Effectiveness*

*Benefit wood products extended rotation (t CO2) = [(34.5 * 1000) – (30.3 * 1000)] * (44/12) * 1*
$$= 15,253.1$$

Total benefits *(t CO2) = (Benefit long term live biomass extended rotation + Benefit wood products extended rotation)*

Total benefits *(t CO2) = 45,601.9 + 15,253.1*
$$= 60,854.9$$

In this hypothetical example where 1000 ha of broadleaved species are managed in an even-aged plantation in the Kakheti region of Georgia, extending the rotation from 51 years to 56 years under the project activity, with a 100% effectiveness rating, the resulting carbon benefits was estimated to be **60,855 t CO$_2$e** for the focal year.

7. OVERRIDING REQUIRED INPUTS DATA

7.1 UNEVEN-AGED FOREST MANAGEMENT

The Uneven-Aged FM tool allows users to override various data sources used in the calculations, such as:

- Rotation length (yr)
- Annual harvest area (ha yr^{-1})
- Extraction rate before intervention (m^3 ha^{-1} yr^{-1})
- Extraction rate after intervention (m^3 ha^{-1} yr^{-1})
- Average wood density (g cm^{-3} or t m^{-3})
- Wood products fraction
    - Sawnwood
    - Roundwood

- o   Woodbased panels
- o   Pulp and paper

Given the investment demand of uneven-aged forest management activities prior to implementation of the activity itself, it is expected that users will have project-specific data on rotation length (RL), annual harvest area (AHA), and extraction rates before and after project intervention (VolExt_after and VolExt_before). The likely availability of one or more of these data would result in much more accurate estimates of carbon benefits from improved forest management practices, especially when considering that some of the data sources provided are at country, or even continent scale. Thus, users are encouraged to use project-specific data whenever possible.

7.2 EVEN-AGED FOREST MANAGEMENT

The Even-Aged FM tool allows users to override various data sources used in the calculations, such as:

- Aboveground biomass at end of rotation in tons of dry mass per hectare (t d.m. ha-1)
- Total baseline live biomass in tons of dry mass per hectare (t d.m. ha-1)
- Aboveground biomass at end of extended rotation in tons of dry mass per hectare (t d.m. ha-1)
- Biomass growth rate
- Length of regular rotation (years)
- Length of extended rotation
- Biomass growth rate (users will be able to choose from a dropdown menu of species for which there are species-specific growth rates in the database or enter their own growth rate estimate)
- Mill conversion efficiency
- Wood product produced (users will be able to choose from a dropdown menu)
    - Single Family Homes
    - Multi Family Homes
    - Mobile Homes
    - Non Residential Construction
    - Pallets
    - Manufacturing
    - Furniture
    - Railroad Ties
    - Paper (free sheet – i.e. long lived publications)
    - Paper (all other)

Given the investment demand of even-aged forest management activities prior to implementation of the activity itself, it is expected that users will have project-specific data on initial rotation length (RL) and the extended rotation length (ERL). The availability of these data would result in much more accurate estimates of carbon benefits from improved forest management practices, especially when considering that some of the data sources provided are at country, or even continent scale. Thus, users are encouraged to use project-specific data whenever possible.

8. REFERENCES

FAO. 1993. Forest resources assessment 1990. FAO Forestry Paper 112, pp.59.

FAO Faostat. Available at: http://faostat.fao.org/site/626/default.aspx#ancor

FAO Global forest resource assessment (FRA). 2010. Country reports. Available at: http://www.fao.org/forestry/fra/en/

Holmes, T.P., G.M. Blate, J.C. Zweede, R. Pereira Jr, P. Barreto, F. Boltz, and R. Bauch. 2002. Financial and ecological indicators of reduced impact logging performance in the eastern Amazon. Forest Ecology and Management 163: 93-110.

IPCC. 2003. IPCC Good Practice Guidance for Land Use, and Forestry. Institute for Global Environmental Strategies, Hayama Japan. Land-Use Change Available at: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.html

IPCC. 2006. Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Uses. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan. Volume 4 Agriculture, Forestry and Other Land Use. Paustian, K, Ravindranath, N.H. and Van Amstel, A (coordinating lead authors). Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Del Lungo A., et. al. 2006. Global planted forests thematic study: results and analysis, by Planted Forests and Trees Working Paper 38. FAO. Rome. Available at www.fao.org/forestry/site/10368/en.

Medjibe V. P., and F. E. Putz. 2012. Cost comparison of reduced-impact and conventional logging in the tropics. Journal of Forest Economics, 18(3): 242-256 pp.

Medjibe V. P., F. E. Putz, M. P. Starkey, A. A. Ndouna, and H. R. Memiaghe. 2011. Impacts of selective logging on above-ground forest biomass in the Monts de Cristal in Gabon. Forest Ecology and Management, 262: 1799-1806 pp.

Mokany, K, Raison, JR, Prokushkin, A.S. 2006. Critical analysis of root:shoot rations in terrestrial biomes. *Global Change Biology* 12: 84-96.

Pearson T.R.H. et al 2014. Carbon emissions from tropical forest degradation caused by logging. Environ. Res. Lett. 9 034017. Available at: http://iopscience.iop.org/1748-9326/9/3/034017/

Pereira, R. Jr, J. Zweede, G.P. Asner, and M. Keller. 2002. Forest canopy damage and recovery in reduced-impact and conventional selective logging in eastern Para, Brazil. Forest Ecology and Management 168: 77-89.

Pinard, M.A., F.E. Putz, J. Tay, and T.E. Sullivan. 1995. Creating timber harvest guidelines for a reduced-impact logging project in Malaysia. Journal of Forestry 41-45.

Pinard, M.A. and F.E. Putz. 1996. Retaining forest biomass by reducing logging damage. Biotropica 28: 278-295.

Putz, E. F., P. A. Zuidema, T. Synnott, M. Pena-Claros, M. A. Pinard, D. Sheil, J. K. Vanclay, P. Sist, S. Gourlet-Fleury, B. Griscom, J. Palmer, and R. Zagt. 2012. Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. Conservation Letters, 8 pp.

Reyes, G., S. Brown, J. Chapman, and A.E. Lugo. 1992. Wood densities of tropical tree species. United States Department of Agriculture, 98. Forest Service Southern Forest Experimental Station, New Orleans, Louisiana. General Technical Report SO-88.

Skog, K.E., Nicholson, G.A., 2000. Carbon Sequestration in Wood and Paper Products. USDA Forest Service Gen. Tech. Rep. RMRS-GTR-59, Chapter 5.

Winjum, J. K., S. Brown, and B. Schlamadinger. 1998. Forest harvests and wood products: sources and sinks of atmospheric carbon dioxide. Forest Science 44:272-284.

ANNEX I

Table 3 Even-Aged FM rotation lengths and sources.

Species	Climate Type	Region	Countries in region RL applied to	RL		Sources
Conifer	Boreal				No default data	
Beech	Cool Temperate	Europe & Eurasia	All in Europe and Eurasia	120	Fagus sylvatica RL for Europe	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
Larch	Cool Temperate	Europe & Eurasia	All in Europe and Eurasia	51	Larix spp. RL for Europe	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Asia and the Near East	China, Mongolia, Afghanistan, Iraq, Lebanon, Palenstina, Syria, Yemen, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan	51	Larix spp. RL for East Asia. Also applied to W. & C. Asia	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Spruce	Cool Temperate	Asia and the Near East	China, Mongolia, Afghanistan, Iraq, Lebanon, Palenstina, Syria, Yemen, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan	70	Picea asperata RL for East Asia. Also applied to W. & C. Asia	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6b
		Europe & Eurasia	All in Europe and Eurasia	76	Picea abies RL for Europe	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6b
Pine	Cool Temperate	Europe & Eurasia	All in Europe and Eurasia	38.5	Pinus spp. RL for Europe	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Latin American and the Caribbean	All in Europe and Eurasia	38.5	Pinus spp. RL for South America, applied to all LAC countries	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands	38.5	Pinus spp. RL for South & Southeast Asia. Applied to Oceania as well (PNG, Vanuatu, Solomon Islands)	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Sub-Saharan Africa	All in Sub-Saharan Africa	38.5	Pine spp. For Eastern and Southern Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Chestnut	Cool Temperate	Asia and the Near East	China, Mongolia, Afghanistan, Iraq, Lebanon, Palenstina, Syria, Yemen,	35	Castanea mollissima for East Asia	2006 Global Planted Forests Thematic Study. Results and

			Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan			Analysis Annex Table 6a
Cunninghamia	Cool Temperate	Asia and the Near East	China, Mongolia, Afghanistan, Iraq, Lebanon, Palenstina, Syria, Yemen, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan	24	Cunninghamia lanceolata RL for East Asia. Also applied to W.&C. Asia	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Pine	Warm Temperate	Europe & Eurasia	All in Europe and Eurasia	38.5	Pinus spp. RL for Europe	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Latin American and the Caribbean	All in Latin America and the Caribbean	38.5	Pinus spp. RL for South America, applied to all LAC countries	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands	38.5	Pinus spp. RL for South & Southeast Asia. Applied to Oceania as well (PNG, Vanuatu, Solomon Islands)	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Sub-Saharan Africa	All in Sub-Saharan Africa	38.5	Pine spp. Rl for Eastern and Southern Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Slash Pine	Warm Temperate	Sub-Saharan Africa	All in Sub-Saharan Africa	30	Pinus elliottii RL for 'East and South Africa' applied to all countries in Sub-Saharan Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
		Latin American and the Caribbean	All in Latin America and the Caribbean	27	Pinus elliottii RL for 'North and Central America' but were applied to all LAC countries in database	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Loblolly pine	Warm Temperate	Latin American and the Caribbean	All in Latin America and the Caribbean	25	Pinus taeda RLs for 'North and Central America' but applied to all LAC countries in database	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
Monterey Pine	Warm Temperate	Sub-Saharan Africa	All in Sub-Saharan Africa	31.5	Pinus radiata RL for 'East and South Africa' applied to all countries in Sub-Saharan Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
		Latin American and the Caribbean	All in Latin America and the Caribbean	23	Pinus radiata RL for South America, but was applied to all LAC countries in database	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
		Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands	28.5	Pinus radiata RL for Oceania region, also applied to S. & S.E. Asia	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
Acacia spp.	Tropical Dry	Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri	15	Acacia spp. RL for South & Southeast Asia. Applied to Oceania as well (PNG, Vanuatu, Solomon Islands)	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a

			Lanka, PNG, Vanuatu, Solomon Islands			
		Latin American and the Caribbean	All in Latin America and the Caribbean	15	Acacia spp. RL for South America, applied to all LAC countries in database	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Sub-Saharan Africa	All in Sub-Saharan Africa	10.5	Acacia spp. RL for E. & S. Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
Acacia nilotica	Tropical Dry	Asia and the Near East	Algeria, Egypt, Tunisia, Libya, Morocco, Sudan, Western Sahara, Mauritania, Lebanon, Jordan, Syria, Palestina, Yemen	22.5	Acacia nilotical RL for North Africa. Also applied to Lebanon, Jordan, Syria, Palestina, Yemen. Also applied to Sub-Saharan Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
	Tropical Dry	Sub-Saharan Africa	All in Sub-Saharan Africa	22.5	Acacia nilotical RL for North Africa applied to Sub-Saharan Africa	2007 Global Planted Forests Thematic Study. Results and Analysis Table 13
Acacia senegal	Tropical Dry	Asia and the Near East	Algeria, Egypt, Tunisia, Libya, Morocco, Sudan, Western Sahara, Mauritania	27.5	Acacia senegal RL for North Africa. Also applied to Lebanon, Jordan, Syria, Palestina, Yemen	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
	Tropical Dry	Sub-Saharan Africa	All in Sub-Saharan Africa	27.5	Acacia nilotical RL for North Africa applied to Sub-Saharan Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
Acacia seyal	Tropical Dry	Asia and the Near East	Algeria, Egypt, Tunisia, Libya, Morocco, Sudan, Western Sahara, Mauritania	20	Acacia seyal RL for North Africa. Also applied to Lebanon, Jordan, Syria, Palestina, Yemen	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
	Tropical Dry	Sub-Saharan Africa	All in Sub-Saharan Africa	20	Acacia nilotica RL for North Africa applied to Sub-Saharan Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
Ailantus excelsa	Tropical Dry	Asia and the Near East	Algeria, Egypt, Tunisia, Libya, Morocco, Sudan, Western Sahara, Mauritania	25	Ailantus spp. RL for North Africa. Also applied to Lebanon, Jordan, Syria, Palestina, Yemen	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Cypress	Tropical Dry	Asia and the Near East	Afghanistan, Iraq, Lebanon, Palenstina, Syria, Yemen, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan	24	Cunninghamia lanceolata RL for East Asia. Also applied to West & Central Asia	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6b
		Asia and the Near East	Algeria, Egypt, Tunisia, Libya, Morocco, Sudan, Western Sahara, Mauritania	47.5	Cupressus spp. RL for North Africa. Also applied to Lebanon, Jordan, Syria, Palestina, Yemen	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Khaya	Tropical Dry	Asia and the Near East	Algeria, Egypt, Tunisia, Libya, Morocco, Sudan, Western Sahara, Mauritania	57.5	Khaya spp. RL for North Africa. Also applied to Lebanon, Jordan, Syria, Palenstina, Yemen	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Teak	Tropical Dry	Latin American and the Caribbean	All in Latin America and the Caribbean	46	Tectona grandis RL for South America, applied to all LAC countries in database	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a

		Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands	50	Tectona grandis RL for South & Southeast Asia. Applied to Oceania as well (PNG, Vanuatu, Solomon Islands)	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Asia and the Near East	Algeria, Egypt, Tunisia, Libya, Morocco, Sudan, Western Sahara, Mauritania	46	Tectona grandis RL for North Africa, also applied to Lebanon, Jordan, Syria, Palestina, Yemen	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Slash Pine	Tropical Dry	Sub-Saharan Africa	all	30	Pinus elliottii RL for 'East and South Africa' applied to all countries in Sub-Saharan Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
		Latin American and the Caribbean	All in Latin America and the Caribbean	27	Pinus elliottii RL for 'North and Central America' but were applied to all LAC countries in database	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Mexican Weeping Pine	Tropical Dry	Sub-Saharan Africa	all	27.5	Pinus patula RL for 'East and South Africa' applied to all countries in Sub-Saharan Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
		Global default	All except Sub-Saharan Africa	21	Pinus patula RL	Silviculture in the Tropics (2011) Book http://books.google.com/books?id=4Xw0ArgjQHsC&pg=PA438&lpg=PA438&dq=Pinus+patula+rotation+length&source=bl&ots=0eziAw4vfj&sig=IZHAoTCZ30G0Df_380Smp_dAv1k&hl=en&sa=X&ei=5bb7Ur38EeG22AWVg4H4Bw&ved=0CDEQ6AEwATgK#v=onepage&q=Pinus%20patula%20rotation%20length&f=false
Monterey Pine	Warm Temperate	Sub-Saharan Africa	all	31.5	Pinus radiata RL for 'East and South Africa' applied to all countries in Sub-Saharan Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
		Latin American and the Caribbean	all	23	Pinus radiata RL for South America, but was applied to all LAC countries in database	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
		Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands	28.5	Pinus radiata RL for Oceania region, also applied to S. & S.E. Asia	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
Agathis	Tropical Moist-wet	Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands	30	Agathis spp. RL for South & Southeast Asia. Applied to Oceania as well (PNG, Vanuatu, Solomon Islands)	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Araucaria	Tropical Moist-wet	Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor,	50	Araucaria spp. RL for Oceania. Also applied to S. and S.E. Asia	2006 Global Planted Forests Thematic Study. Results and

			Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands			Analysis Annex Table 6a
		Latin American and the Caribbean	all	14	Araucaria angustifolia RL for South America, applied to all LAC countries	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Gmelina	Tropical Moist-wet	Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands	24	Gmelina arboria RL for South & Southeast Asia. Also applied to Oceania (PNG, Vanuatu, Solomon Islands)	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Global default	all	16.5	Gmelina arboria RL	S. Günter, M Weber, B Stimm, R. Mosandi (2011). Silviculture in the Tropics. Springer, New York.
Rubber	Tropical Moist-wet	Global default	all	30	United Nations Conference on Trade and Development website	http://r0.unctad.org/infocomm/angl ais/rubber/crop.htm
Pine	Tropical Moist-wet	Europe & Eurasia	all	38.5	Pinus spp. RL for Europe	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Latin American and the Caribbean	all	38.5	Pinus spp. RL for South America, applied to all LAC countries	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Afghanistan, Bangladesh, India, Iran, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands	38.5	Pinus spp. RL for South & Southeast Asia. Applied to Oceania as well (PNG, Vanuatu, Solomon Islands)	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Asia and the Near East	China, Mongolia	22.5	Pinus massoniana RL for E. Asia (based on Table 12 data that this species makes up 24% of species grown in production forests)	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Sub-Saharan Africa	all	38.5	Pine spp. For Eastern and Southern Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Pterocarpus	Tropical Moist-wet	Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands	37.5	Pterocarpus indicus RL for South & Southeast Asia. Also applied to Oceania (PNG, Vanuatu, Solomon Islands)	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6b
Mahogany	Tropical Moist-wet	Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands	39.5	Swietenia macrophylla RL for South & Southeast Asia. Also applied to Oceania (PNG, Vanuatu, Solomon Islands)	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6b

		Global default	All except the countries listed above	50	Swietenia macrophylla RL	S. Günter, M Weber, B Stimm, R. Mosandi (2011). Silviculture in the Tropics. Springer, New York.
Teak	Tropical Moist-wet	Latin American and the Caribbean	all	46	Tectona grandis RL for South America, but was applied to all LAC countries in database	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands	50	Tectona grandis RL for South & Southeast Asia. Also applied to Oceania (PNG, vanuatu, Solomon Islands)	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
		Asia and the Near East	Algeria, Egypt, Tunisia, Libya, Morocco, Sudan, Western Sahara, Mauritania	46	Tectona grandis RL for North Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
Eucalyptus	Tropical Moist-wet	Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka, PNG, Vanuatu, Solomon Islands	11	Eucalyptus spp. RL for South & Southeast Asia. Also applied to Oceania (PNG, Vanuatu, Solomon Islands)	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Asia and the Near East	Algeria, Egypt, Tunisia, Libya, Morocco, Sudan, Western Sahara, Mauritania	11	Eucalyptus spp. RL for North Africa, also applied to Lebanon, Syria, Jordan, Palestina	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Asia and the Near East	China, Mongolia	11	Eucalyptus spp. RL for East Asia	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a
		Sub-Saharan Africa	all	8	Eucalyptus grandis & Eucalyptus nitens RL for E. & S. Africa	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
		Latin American and the Caribbean	all	11	Eucalyptus spp. RL for S. America, applied to all LAC countries	2006 Global Planted Forests Thematic Study. Results and Analysis Table 13
		Asia and the Near East	Afghanistan, Iraq, Lebanon, Palenstina, Syria, Yemen, Oman, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan	11	Eucaluptus Spp. For W.&C. Asia	2006 Global Planted Forests Thematic Study. Results and Analysis Annex Table 6a

ANNEX II

Table 4 Default growth rates for conifer and broadleaf species by region

Region	Countries	Default Conifer species	Default Broadleaf species	Conifer_ MAX	Conifer _k	Conifer_ _m	Conifer _RL	Broadleaf_ MAX	Broadleaf_ _k	Broadleaf_ m	Broadleaf_ RL
Europe & Eurasia	all	Pine spp.	Larch	185	0.027	0.63	38.5	481.25	0.024	0.63	51
Sub-Saharan Africa	all	Mexican weeping pine	Eucalyptus	257.8	0.085	0.63	27.5	311.72	0.241	0.63	8
Asia and the Near East	Indonesia, Cambodia, Laos, Myanmar, Thailand, Vietnam, Malaysia, East Timor, Philippines, Singapore, Bhutan, Bangladesh, India, Nepal, Pakistan, Sri Lanka	Pine spp.	Teak	154.6	0.195	0.63	38.5	315	0.056	0.63	24
Asia and the Near East	Algeria, Egypt, Tunisia, Libya, Morocco, Sudan, Western Sahara, Mauritania	Pine spp.	Acacia senegal	250.9	0.098	0.63	38.5	60	0.092	0.63	27.5
Asia and the Near East	China, Mongolia, Afghanistan, Iraq, Jordan, Lebanon, Palenstina, Syria, Yemen, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan	Cunninghamia lanceolata	Casteanea mollissima	221.5	0.113	0.63	24	177.2	0.027	0.63	35
Asia and the Near East	Papua New Guinea, Solomon Islands, Vanuatu	Pine spp.	Eucalyptus	154.6	0.195	0.63	38.5	311.72	0.241	0.63	11
Latin America and the Caribbean	all	Pine spp.	Eucalyptus	154.6	0.195	0.63	38.5	311.72	0.241	0.63	11

For questions and comments:

Felipe M. Casarim Carbon Specialist, Ecosystem Services

Winrock International **|** 2121 Crystal Drive, Suite 500 **|** Arlington, VA 22202, USA **|** www.winrock.org

office 703.302.6538 **|** fax 703.302.6512 **|** e-mail fcasarim@winrock.org