

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



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**The AFOLU Carbon Calculator**



# AFOLU CARBON CALCULATOR

## THE FOREST PROTECTION TOOL: UNDERLYING DATA AND METHODS

Winrock International

December, 2014

This publication was produced for review by the United States Agency for International Development. Prepared by Winrock International under the Cooperative Agreement No. EEM-A-00-06-00024-00.

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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.

## *Cite report as:*

Winrock International. 2014. AFOLU Carbon Calculator Series. The Forest Protection Tool: Underlying Data and Methods. Prepared by Winrock International under the Cooperative Agreement No. EEM-A-00-06-00024-00.

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## **I. SCOPE**

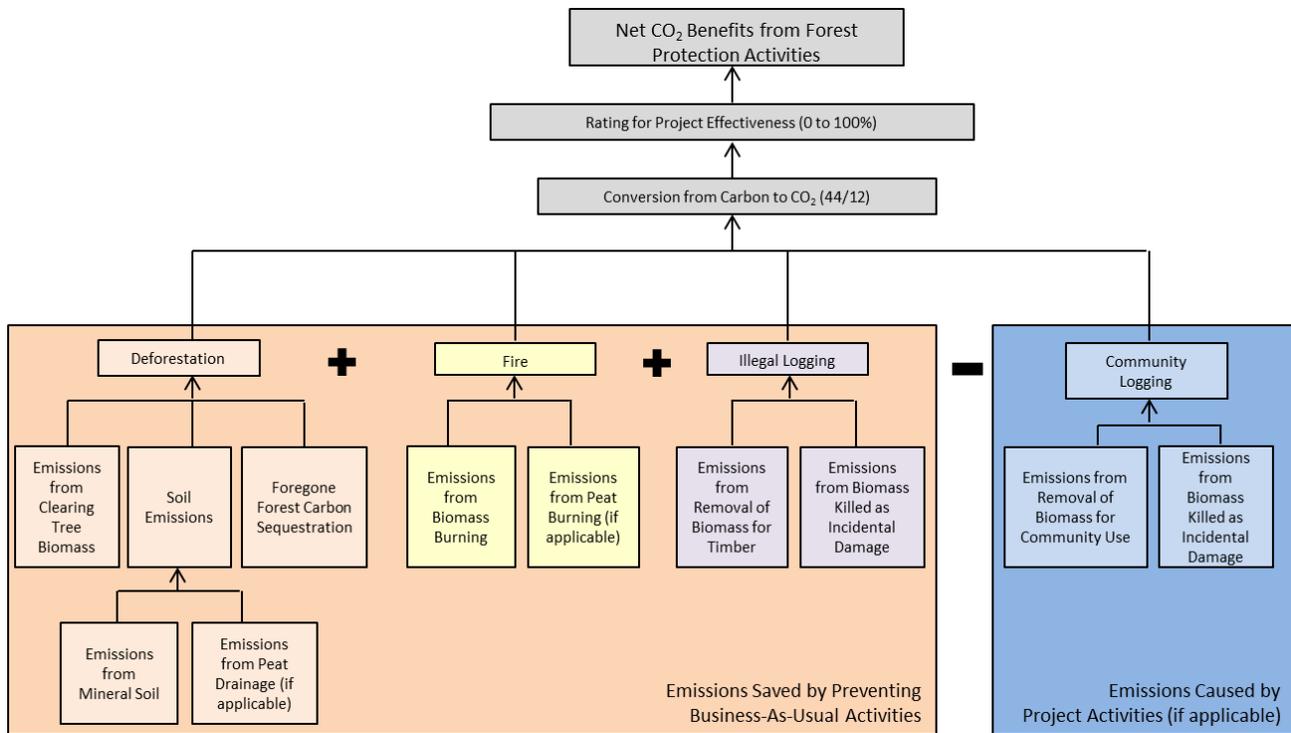
This document describes the underlying data sources and calculation methods employed in the Forest Protection (FP) Tool of the AFOLU Carbon Calculator (<http://afolucarbon.org/>). The FP tool is designed for project activities that aim at reducing greenhouse gas (GHG) emissions from deforestation, and/or forest degradation through fires or illegal logging.

## **2. APPLICABILITY**

The FP tool is applicable to avoided deforestation or avoided degradation activities that will reduce GHG emissions and maintain forest stocks. The project activities include those that protect the forests from deforestation, forest fires and/or illegal logging, while also accounting for emissions from community forestry practices within protected forests if applicable. The FP tool accounts for uptake of atmospheric carbon in forest areas that would be deforested (i.e. foregone sequestration). The FP tool can also calculate the benefits of avoiding deforestation in mangrove forests and associated foregone sequestration.

## **3. APPROACH TO THE FOREST PROTECTION TOOL**

The FP tool employs the basic IPCC approach of combining activity data with emission factors. The greenhouse gas benefit of forest protection activities represents the sum of benefits from reducing deforestation (including foregone sequestration), reducing fire incidence and reducing illegal logging, minus any emissions that occur as a result of community forestry activities within the project area (Figure 1).



**Figure 1. Flowchart showing the individual components of the Forest Protection calculator. Note that foregone sequestration is included only for deforestation; accurate values are unknown for fire and illegal logging and are likely *de minimis*. For mangrove the same process applies except only deforestation is accounted for.**

Activity data used for calculations in the FP tool include, as appropriate, area deforested or burned ( $\text{ha yr}^{-1}$ ), annual volume of wood illegally extracted ( $\text{m}^3 \text{ha}^{-1}$ ), proportion of area in peat (%), depth of peat drainage (m) and peat burning (m). The emission factors include the live tree biomass (above- and below-ground) and soils (including peat). It is assumed that post-deforestation carbon stocks are zero. Foregone sequestration and emission factors from biomass burning use IPCC (2006) defaults<sup>1</sup>.

The default activity-type is the protection of forest against deforestation. Thus, if a user enters only the project area, location, and management effectiveness rating under 'Required Inputs', **benefits will be calculated only for reducing deforestation** from a forested project area. Users can change the vegetation type being protected. The options are forest (default), peat forest or mangroves. Selecting peat forest means that in addition to the forest emissions, emissions from draining peat are also accounted for. Deforestation is the total conversion of forest to non-forest, and should not be confused with forest degradation. Forest degradation includes activities that result in carbon stock reductions (such as illegal logging), but not complete conversion from forested to non-forest. Users can change or add activity types from protection against deforestation to protection against illegal logging and/or protection against fire.

If protection against illegal logging and/or fire is chosen, users are encouraged to enter project-specific data under 'Advanced Inputs'. Users can also change the vegetation type being protected. The options

<sup>1</sup> Available at: <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html>

are forest (default), peat forest or mangroves. Selecting peat forest means that in addition to the forest emissions, emissions from draining and burning peat are also accounted for when deforestation is selected as the activity type and that burning of peat is accounted for when avoiding fire is selected as the activity type.

In the calculations, we assume that where multiple activity types are chosen (protection against deforestation and fire for instance), the areas within the administrative unit that would have been deforested and burned in the business-as-usual scenario do not overlap. This simplifying assumption is necessary to avoid double-counting of project benefits.

Data from various sources were compiled for providing robust estimates of reduced emissions from forest protection activities throughout the AFOLU Carbon Calculator's country list (currently composed of 119 countries). These sources are described in the following section of this document.

## 4. DATA SOURCES

### 4.1. DEFORESTATION RATE

An important distinction when calculating deforestation rates is the difference between gross and net deforestation. Gross deforestation is calculated based on the proportion of an original quantity of forested area that is converted to non-forest over a specified time period, while net deforestation is calculated based on the difference in total forest area between two points in time. In other words, gross deforestation measures forest loss areas irrespective of regrowth, while net deforestation examines the balance of both forest losses (deforestation) and forest gains (regrowth).

Default rates of gross deforestation, based on published data, are provided by the FP tool. However, users may alter these rates with known values under required inputs, when available. In addition, users may enter the *ex-post* deforestation rate, or the rate of deforestation after the project is implemented. While this rate will be lower than the *ex-ante* rate of deforestation, it is unlikely to be zero. The *ex-ante* deforestation rate is then subtracted from the *ex-post* rate, resulting in the rate which is used in subsequent calculation of benefits.

#### 4.1.1 DEFORESTATION OF FORESTS

In the FP tool, historical rates of gross deforestation within each jurisdiction were estimated by summing pixels of apparent deforestation in a raster-based forest loss dataset, averaging total loss over the years covered by the dataset, and converting number of pixels into hectares. Final deforestation rates are expressed as a percentage loss per year (% yr<sup>-1</sup>), where the denominator is the total area of forest in the earliest available year (in this case 2000).

Ideally, forest cover maps created specifically for individual countries would be used, to take into account local forest definitions and ecological factors. However, these data are not available for all countries covered by the FP tool, and where they do exist, are created at inconsistent resolutions and

time periods. Therefore, gross deforestation rates for all countries were calculated from a single global medium-resolution source, the 2013 Hansen et al. forest cover change layer<sup>2</sup>.

Hansen et al. analyzed the entire global archive of Landsat imagery from 2000-2012 and identified areas of deforestation. For each pixel, the dataset identifies whether deforestation occurred during 2000-2012, as well as the year of disturbance. The dataset also includes a layer depicting tree canopy density, ranging from 0% to over 90%. The forest loss layers were used in the FP tool to calculate historical rates of gross deforestation, in hectares. In order to convert hectares to percent, a definition of forested area in 2000 is needed. For this value, a forest/non-forest mask was created based on Hansen et al. canopy density. A cutoff of 15% density was chosen as the definition of forest for all countries. All pixels with a canopy density of 15% or higher were classified as forest in 2000. This forest/non-forest mask was used as the definition of forested area in 2000, and was also used to exclude deforested pixels that occurred on very low canopy density areas. Zonal statistics were used within each subnational jurisdiction to calculate the total area of: 1) 2000 forests; and 2) forest loss from 2000-2012 occurring on areas of canopy cover greater than 15% in 2000.

Final rates of deforestation for each jurisdiction were calculated as follows:

$$D = \frac{A_{def}}{A_{forest} * y}$$

Where

$D$  = annual rate of gross deforestation (%)

$A_{def}$  = total area of gross deforestation  $t_1$ - $t_2$ , 2000-2012

$A_{forest}$  = area of forest at  $t_1$ , 2000

$y$  = Number of years represented by the deforestation dataset. 12 based on Hansen et al. (2013)

#### 4.1.2 DEFORESTATION OF MANGROVE FORESTS

The FAO (2007) provides data, at the national level, for total mangrove area and net rate of change for 1980, 1990, 2000 and 2005. Rate and area values were compiled from approximately 2,900 national and subnational data sets. Because data at the national level were collected at different times, current rates of deforestation were extrapolated based on the most recent recorded data for a given country. The most recent time period, 2000-2005, was used because it is presumed to be most indicative of current rates. Because data on gross rate of change in mangrove forests are not available, FAO net rate of change was used.

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<sup>2</sup> The data are currently available for free download from the University of Maryland at <http://earthenginepartners.appspot.com/science-2013-global-forest>

## 4.2. CARBON STOCKS

### 4.2.1 FOREST CARBON STOCKS

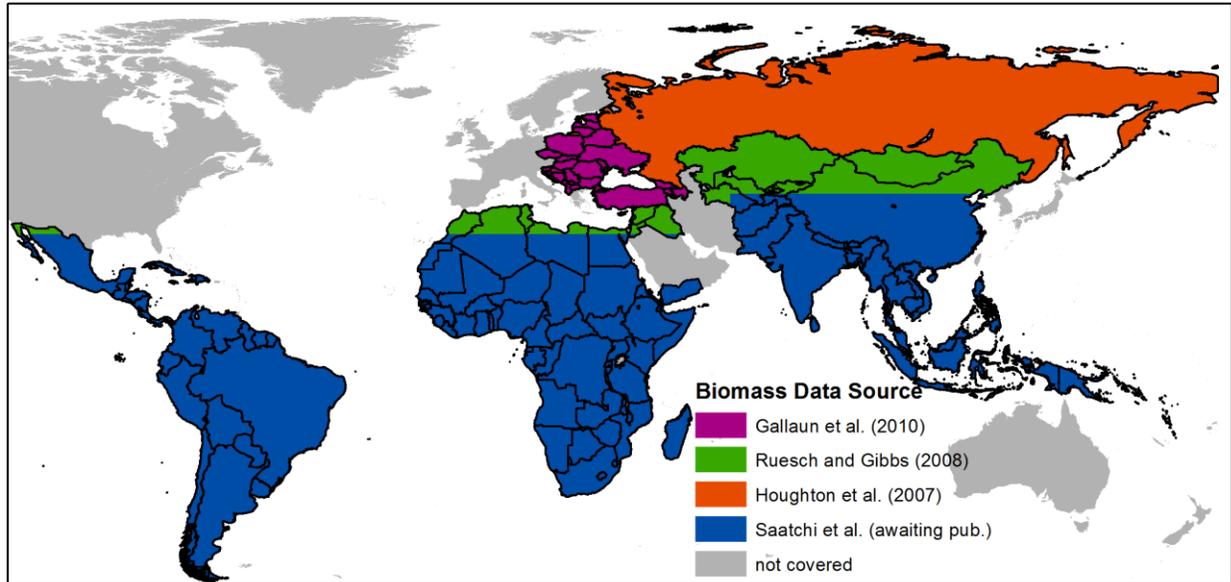
Maps of carbon density are critical inputs for estimating carbon emissions from deforestation and degradation of tropical forests, yet few reliable estimates of forest carbon stocks exist on a global, or even continent-wide, scale. Average forest carbon stocks (including both above and belowground biomass) per administrative unit were calculated (in units of t C ha<sup>-1</sup>) using a number of different regional and global datasets, outlined below. In each dataset, carbon density values were aligned to the extent of forest area. Forest was defined by applying a 15% minimum cutoff to Hansen et al (2013)'s canopy density layer. For a given subnational jurisdiction, the average carbon stock was calculated as the area-weighted average (AWA) of carbon within *forested* cells.

**Sub-Saharan Africa, Latin America, South and Southeast Asia:** Saatchi and colleagues (in prep.) developed a map of aboveground forest biomass for the year 2005 for countries across the tropics at 250m resolution. Their approach used a combination of ground inventory biomass plots and remote sensing derived metrics including forest heights measured by spaceborne LIDAR (from the ICESat-GLAS satellite), and a suite of optical and microwave satellite imagery products. This map is the most consistent, spatially-refined map of forest carbon stocks available to date.

**Eastern Europe, Turkey and the Caucasus:** We used a map of above ground biomass produced by Gallaun et al. (2010). This dataset depicts '000s tonnes of carbon per 10km×10km grid cells (or 10,000 ha). Values were recalculated to express t C ha<sup>-1</sup>.

**Russia:** We used a map of total above and belowground forest biomass in Russia produced by Houghton et al. (2007) to estimate forest carbon stocks by administrative district. Houghton et al. used regression-tree analyses to relate local forest inventory data to data from the MODIS satellite bidirectional reflectance distribution function (BRDF) product (MOD43B4). The Houghton et al. biomass product was converted to carbon stocks (carbon = biomass \* 0.47).

**Other:** Ruesch et al. (2008) developed estimates of forest biomass carbon stocks in the year 2000 by assigning Tier I IPCC values to FAO ecological zones. Area-weighted carbon stocks were estimated by administrative unit in countries where no other region-specific estimates were available (e.g., Western Asia, Central Asia).



**Figure 2. Coverage of biomass datasets used in calculation of average carbon stocks,**

Where only aboveground biomass was estimated (Ruesch and Gibbs 2008), the belowground biomass component was added in to produce estimates of total biomass carbon stocks based on an equation (2) in Mokany et al. (2006) that relates belowground biomass to aboveground biomass.

$$BGB = 0.489 * AGB^{0.890} \quad (2)$$

Where:

*BGB* = Belowground biomass (t C)

*AGB* = Aboveground biomass (t C)

#### 4.2.2 MANGROVE FOREST CARBON STOCKS

Literature reviews and discussions with other scientists who study mangroves produced a number of options for estimating mangrove biomass values to use in the AFOLU Carbon Calculator. Three options were chosen as the most appropriate based on the completeness and consistency of the datasets.

Fatoyinbo (pers. comm. and Fatoyinbo and Simard 2012) provided country-specific biomass data for numerous African countries. Because these estimates are for entire countries, rather than sub-administrative units, an area weighted average was developed for each relevant sub-administrative unit.

Because the country-specific values are only available for certain African countries, mangrove biomass for other relevant countries was derived from a global map of mangrove biomass potential from Hutchison et al. (2013).

For any remaining areas where mangroves are likely to exist, but are not represented in existing biomass datasets, mangrove biomass is estimated using Twilley et al.'s (1992) biomass equation:

$$AGB_{Man} = 298.5 - 7.2918 * LAT \quad (R^2 = 0.56) \quad (3)$$

Where:

$AGB_{Man}$  = aboveground mangrove biomass in metric tons per hectare and

LAT = the absolute value of the Latitude at the midpoint of the sub-administrative unit's coastal region.

Belowground biomass for all mangroves was calculated based on a ratio defined by Twilley et al (1992):

$$BGB = AGB * 0.608 \quad (4)$$

Where:

BGB = belowground biomass in metric tons per hectare,

AGB = aboveground biomass in metric tons per hectare.

### 4.3. SOIL EMISSIONS

When forest land is cleared for agriculture on mineral soils, tillage of the soil disturbs the top layer and results in soil carbon emissions. On peat soils, which are generally flooded for most of the year, conversion to agriculture requires drainage of the top layer and often burning before crops can be planted. Drainage of peat results in ongoing CO<sub>2</sub> emissions as the peat is oxidized by the air, whilst burning releases a single pulse of emissions. Non-CO<sub>2</sub> emissions due to peat draining or burning are not accounted for in the tool. This is due to the dominance of CO<sub>2</sub> in the GHG emissions profiles (Agus et al., 2013).

#### **Peat Soils (only applicable when Peat Forest is selected as the vegetation type)**

The approach used to calculate peat emissions associated with deforestation assumed that for the portion of the area that is peat drainage and an initial burn occurs. The drainage causes emissions every year during which the area is deforested, whilst the initial burn releases a pulse of emissions in the year of conversion. The data sources used in the tool are explained below.

**Peat coverage:** Default values for peat percentage are provided in the calculator as the percentage of the total area of each administrative unit that contains peat soils. For Indonesia, these percentages were calculated in a GIS using a peatland data layer produced specifically for Indonesia by Wetlands International. For Malaysia, these percentages were calculated using a global wetlands map produced by the USDA NRCS. However, the percentage of the project area that is on peat should be specified by the user under 'Advanced Inputs'.

#### **Peat burning emissions**

The emissions from peat burning are the product of the area cleared, the depth of peat burnt and its carbon density.

**Peat burn depth:** In a review of current literature, Agust et al., 2013 found estimates of the impacts of the depth of fire on peat soils are dominated by a limited number of studies that have focused on observations made during El Niño years in Central Kalimantan. These values range from approximately 50 cm in 1997 (Page et al., 2002) to 39 cm in 2002 (Usup et al., 2004) and 33 cm in 2006 (Balhorn et al., 2009). They recommend using conservative values for peat fires over decadal time periods that span both wet and dry years. Specifically, they suggest that the average depth of a peat fire would be 15 cm for swamp forest. Therefore we assumed 15 cm as the burn depth, but acknowledge in el Niño years this value could be much higher.

**Carbon bulk density of peat:** A value of 0.06 t C m<sup>-3</sup> from Page et al., 2012 is used.

### Peat drainage emissions

The emissions from peat draining are the product of the area cleared, the depth of peat drainage and an emissions factor.

**Drainage Depth:** The default drainage depth value was assumed to be 0.6 m. Peat is most commonly drained for palm oil, rubber and timber production. The Roundtable for Sustainable Palm Oil recommend a drainage depth of 0.4-0.6 m, in order to maximizes plant productivity and minimize CO<sub>2</sub> emissions. In many plantations, water table depths are not actively managed and often fall below 0.8 m during the annual dry season, particularly during periods of severe drought (Lim et al., 2012). A technical report to the RSPO (Agus et al., 2013) recommends a drainage depth of 0.6 m is used when estimating emissions from Palm Oil. Agus et al. estimate 0.5 m to be the drainage depth commonly maintained for rubber and timber production on peatlands. In ‘Advanced Inputs’ users can adjust the drainage depth from the default of 0.6 m.

**Emissions Factor for drained peat:** Hooijer et al. (2006, 2010) developed a model that correlates drainage depth with CO<sub>2</sub> emissions. The model estimates that for every 1 cm of drainage depth there is an emission of about 0.91 t CO<sub>2</sub> ha<sup>-1</sup> yr<sup>-1</sup>. Agus et al. (2013) highlight that this relationship is based largely on experiments using closed chambers in which there was no separation between autotrophic respiration mediated by roots and heterotrophic respiration linked to microbial decomposition. Therefore, in order to avoid over estimating CO<sub>2</sub> emissions by using total soil respiration, Agus et al. recommend using the emission factor developed by Hooijer et al. (2010) modified by a coefficient of 0.79 to correct for the root-related emission based on the studies of Jauhiainen et al. (2012). Therefore a corrected emissions factor of 0.72 t CO<sub>2</sub> cm<sup>-1</sup> ha<sup>-1</sup> yr<sup>-1</sup> is used in the calculation section below.

### Mineral Soils

Mineral soil carbon stocks before conversion to cropland were estimated using the Harmonized Soil Map of the World v.1.1, available at 1km resolution (each pixel is 100 ha in area). Attribute values of the database did not include average pixel-level soil carbon stocks, but values were included instead for bulk density (g cm<sup>-3</sup>) and carbon content (%C) in both the top 30 cm and top 1.0 m of soil in each grid cell. Here, average soil carbon stocks were calculated in the top 30 cm of soil – the assumed depth to which soil carbon stocks would be affected when converted to agriculture – by multiplying the volume of soil in a given forested hectare (1 ha x 30 cm depth = 3,000 m<sup>3</sup>) in an administrative unit by the bulk density

to calculate the mass of soil in a given forested hectare, then the soil mass was multiplied by the carbon content to derive an average forest soil carbon stock value per hectare ( $t\ C\ ha^{-1}$ ) in each administrative unit.

Soil carbon stocks after forest conversion to cropland were based on specific soil stock change factors for land use, management and inputs ( $F_{LU}$ ,  $F_{MG}$ ,  $F_I$ , respectively) listed in Table 5.10 of the IPCC AFOLU. Relevant factors are listed in Table I. Stock change factors were selected for each land cover type (before and after conversion) and multiplied by reference soil carbon stocks. Following the IPCC AFOLU guidelines, the total difference in carbon stocks before and after conversion provides the difference over 20 years, which is then divided by 20 to produce an annualized number for soil carbon loss. The cropland land use factor ( $F_{LU}$ ) was assumed to be for long-term cultivated crops. Full tillage and medium inputs were assumed in all scenarios of cropland conversion.

**Table I. Relative stock change factors ( $F_{LU}$ ,  $F_{MG}$ ,  $F_I$ ) for different management activities. Based on Tables 5.5 and 5.10 in 2006 IPCC AFOLU.**

Factor value type	Level	Temperature Regime	Moisture Regime	IPCC default
Land use ( $F_{LU}$ )	Long-term cultivated	Temperate/Boreal	Dry	0.8
			Moist	0.69
		Tropical	Dry	0.58
			Moist/Wet	0.48
		Tropical montane	n/a	0.64
Tillage ( $F_{MG}$ )	Full	All	All	1
Input ( $F_I$ )	Medium	All	All	1

#### 4.4. FOREGONE SEQUESTRATION

Over time, trees sequester carbon dioxide from the atmosphere and accumulate carbon as biomass. When forests are converted to another land use, the trees that would have continued to grow are cut down and no longer act as carbon sinks. Therefore, each year after a land use conversion has occurred, the carbon that would have been sequestered in the growing trees is “lost” or “foregone”. In an avoided emissions scenario, carbon benefits can be generated not only from preventing the immediate loss of biomass carbon stocks, but also from allowing carbon to accumulate over time in the vegetation that would have been cleared.

##### 4.4.1 FOREST GROWTH RATES

Average annual biomass accumulation rates for native forest stands are given in Table 4.9 of the 2006 GL AFOLU and are specified according to ecological zone and continent. These values were used to estimate the foregone biomass accumulation of forests that were converted to another land use. Average values were used where a range of values was listed. Foregone carbon accumulation was then

assumed equal to the biomass accumulation value multiplied by the carbon fraction in dry matter (IPCC default = 0.47).

The area of forest in each country (as determined in the MODIS land cover product) was stratified by the FAO ecozone and continent, and appropriate values were applied to calculate an average area-weighted value of foregone forest sequestration per hectare for each administrative unit. Because biomass accumulation rates in Table 4.9 of the 2006 IPCC AFOLU Guidelines are separated into rates for forests that are less than or greater than a 20 year threshold.

#### 4.4.2 MANGROVE FOREST GROWTH RATES

The rate of biomass accumulation for mangroves was assigned using the area-weighted average based on IPCC values for aboveground biomass growth as a function of local climate type, defined by one of the following IPCC classes: Tropical Wet, Tropical Dry, and Subtropical (Table 2).

**Table 2. Aboveground biomass growth in mangrove forests (tonnes DM ha<sup>-1</sup> yr<sup>-1</sup>)<sup>3</sup>**

Domain	Region	N	Aboveground biomass growth	Data Range
Tropical	Tropical Wet	23	9.9	0.1-27.4
	Tropical Dry	6	3.3	0.1-7.5
Subtropical		4	18.1	5.3-29.1

Climate zones were calculated at 30 arc minute resolution using the IPCC climate zone decision tree from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Chapter 3, “Consistent Representation of Lands”). This decision tree delineates climate categories based on Mean Annual Temperature, Mean Annual Precipitation, Potential Evapotranspiration, and Elevation.

**Potential Evapotranspiration** was acquired from the FAO (2004) *Global map of monthly reference evapotranspiration – 10 arc minutes*

Available at <http://www.fao.org/geonetwork/srv/en/main.home>

**Mean Annual Temperature/Precipitation** data were acquired from worldclimate.org at the 30 arc minute. Most of these data are derived from the Global Historical Climatology Network (GHCN), which is a global historical climate database used to monitor climate change.

Available at: <http://www.fao.org/geonetwork/srv/en/main.home>

**Elevation** values were taken from Shuttle Radar Topography Mission (SRTM) “finished grade” at 3 arc second resolution. Data were resampled to the 10 arc minute resolution.

Available at: <http://earthexplorer.usgs.gov/>

<sup>3</sup> IPCC 2014, 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). Published: IPCC, Switzerland.

The resulting climate map contains zones that are not applicable to the mangrove growth rate calculation, such as polar, boreal, temperate and montane classes. Therefore, unused classes were removed, and the remaining classes were grouped into more general categories: Tropical Wet, Tropical Dry, and Subtropical.

Climate zones were reclassified on the following basis:

<b>IPCC Name:</b>	<b>Mangrove Class</b>
Tropical Montane	<i>Case-by-case</i>
Warm Temperate Dry	Subtropical
Warm Temperate Moist	Subtropical
Tropical Dry	Tropical Dry
Tropical Moist	Tropical Wet
Tropical Wet	Tropical Wet
Boreal Dry	n/a
Boreal Moist	n/a
Cool Temperate Dry	n/a
Cool Temperate Moist	n/a
Polar Dry	n/a
Polar Moist	n/a

Due to the coarse resolution of the climate map, there are areas of mangroves with either no corresponding climate zone, or with an inappropriate designation (such as Montane). For these areas, a climate zone was assigned based on the nearest appropriate climate zone.

The nearest applicable climate zone was identified through the calculation of Thiessen polygons from the centroids of Tropical Wet, Tropical Dry and Subtropical pixels.

After creating generalized climate categories and assigning zones to missing areas with Thiessen polygons, many provinces fall into multiple climate zones. Because the C calculator relies on a single growth rate value for each administrative unit, growth rate was calculated as the area weighted average of mangrove growth rates across different climate zones in each administrative unit. Growth rates are calculated with the following equation:

$$\frac{\sum A_i r_i}{\sum A_i}$$

Where

$A_i$ : Area of mangroves in climate zone  $i$

$r_i$ : Growth rate of mangroves in climate zone  $i$

#### 4.5. FIRE

CO<sub>2</sub> emissions from fire are calculated as the sum of emissions from biomass burning and for projects that take place on peat, from peat burning.

##### **Biomass Burning**

Biomass burning is the product of the project area, the fire incidence rate, forest carbon stock, the proportion that combusts and the emissions factor for combustion.

Global burned area data are available for the years 2000 through 2007 (Tansey et al., 2008). The annual proportion of forest burned per administrative unit was calculated for each year by calculating the fraction of forest (as delineated by MODIS land cover data) that had burned each year. A default annual average **fire incidence rate** was then calculated as the average of the 7 years of available data.

Forest carbon stocks were divided by 0.47 first to convert to biomass. We assumed that 34% of the biomass is combusted. This is the most conservative value of combustion factor that the IPCC (2006) provide for any forest type<sup>4</sup>. We then use an emission factor of 1.58 kg CO<sub>2</sub> per kg of dry matter burnt. This is the IPCC (2006) emissions factor for tropical forest, where the majority of forest protection projects will occur.

In this version of the tool, non-CO<sub>2</sub> emissions are conservatively excluded.

##### **Peat Burning**

The emissions from peat burning are the product of the fire incidence rate, the project area, the depth of peat burnt and its carbon density. The same data sources are used as described above in section 4.3 on peat burning associated with clearing.

#### 4.6. ILLEGAL LOGGING AND COMMUNITY LOGGING

The current default for the **rate of illegal logging** and community logging in all administrative units is zero due to a lack of reliable data for most regions of the world. If a user enters project-specific information under 'Advanced Inputs', the total CO<sub>2</sub> benefits from forest protection activities will reflect CO<sub>2</sub> impacts from stopping illegal logging and/or emissions from community forestry activities.

The approach to calculating emissions from illegal and community logging is based on the approach used for planned logging in the Forest Management Tool. The forest management tool uses the following equation:

$$\text{Avoided Emissions logging} = (\text{ExtractedLogs}_{\text{before}} + \text{Incidental Damage}_{\text{conv}} + \text{Logging Infrastructure}_{\text{conv}}) \times 44/12$$

In this tool it is assumed that illegal operating activities use existing roads and forest tracks and have minimal infrastructure. Hence, the equation is simplified to:

$$\text{Avoided Emissions logging} = (\text{ExtractedLogs}_{\text{before}} + \text{Incidental Damage}_{\text{con}}) \times 44/12$$

<sup>4</sup> See section 2.4 in [http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4\\_Volume4/V4\\_02\\_Ch2\\_Generic.pdf](http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf). The calculation method and the default values have been sourced from here.

The same data and methods are used to calculate these components as in the Forest Management tool. The data sources for the extracted log emissions factor (ELE), wood density and logging damage factor that are used in this equation are explained below.

### **Extracted log emissions (ELE) factor**

This factor represents the emissions resulting from conversion of the wood in a log extracted from 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 ( $R^2 = 0.99$ ) between wood density ( $\text{g cm}^{-3}$ ) and ELE ( $\text{t C m}^{-3}$ ):  $ELE = (0.4924 \times WD) - 0.0158$ . 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. Users can overwrite these values in 'Advanced Inputs'.

### **Logging damage factor (LDF)**

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) found a strong correlation ( $R^2 = 0.86$ ) between the biomass carbon stock ( $\text{t C ha}^{-1}$ ) and the logging damage factor ( $\text{t C m}^{-3}$ ):  $LDF = -0.0039(\text{Carbon Stock}) + 1.7817$ . 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 above.

## **5. UNCERTAINTY OF ESTIMATES**

Uncertainty is a property of a parameter estimate and reflects the degree to which there is a lack of knowledge of the true 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  $\pm 10\%$  of the mean (from GOF-C-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 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 GOC-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 GOC-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  $\pm 60\%$
- 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 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%)	
<b>Deforestation of forest</b>	Deforestation rate (% yr <sup>-1</sup> )	<b>X</b>			Hansen et al data base not verified for all countries
	Forest C stocks - Africa, Latin America and SE Asia	At scales of > 10,000 ha	At scales <10,000 ha		As discussed in Saatchi et al 2011
	Forest C stocks - Europe, Turkey, Caucasus and Russia		<b>X</b>		
	Forest C stocks – Other			<b>X</b>	IPCC Tier 1 Default values
	Forest growth rates		<b>X</b>		IPCC default values, adjusted to ecological zone and continent
<b>Deforestation of mangroves</b>	Deforestation rate (% yr <sup>-1</sup> )		<b>X</b>		From FAO data for net rate
	Mangrove C stocks		<b>X</b>		
	Mangrove growth rates		<b>X</b>		
<b>Mineral and peat soil emissions</b>	Mineral soil C stocks		At large scales (admin unit to national)	At small scales of <1,000 ha	Based on Harmonized Soil map of world to 30 cm depth

	Mineral soil change factors		X		
	Peat coverage	For Indonesia and Malaysia			No default values for other countries
	Carbon bulk density of peat	X			BD of peat generally well known
	Peat drainage depth	X			Convergence of agreement based on several key studies
	Emission factor for drained peat		X		
	Peat burn depth	X			
<b>Fire</b>	Fire incidence rate		X		
	Fire combustion factor		X		IPCC default values
	Fire emission factor		X		IPCC default values
<b>Illegal logging and community logging</b>	Extracted log emissions	X			Based on a highly significant relationship from vast field dataset
	Wood density of logs extracted	X			
	Logging damage factor	X			Based on very significant relationship from vast field dataset

As seen in the table above, the uncertainty of the carbon benefit estimates generated using the FP Tool are likely to be low to medium, given the input parameters employed in the calculations have low/medium associated uncertainty. Users can strive for lowering the uncertainty associated with carbon benefits estimated using the FP Tool by overriding the defaults values provided with inputs with a greater level of precision than presented here, as discussed 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:

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

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 area and C stock using the Tier I method:

	Mean value	Uncertainty (% of the mean)
Area change (ha)	10827	8
Carbon stock (t C/ha)	148	15

Thus the total carbon stock loss over the stratum is:

$$10,827 \text{ ha} * 148 \text{ tC/ha} = 1,602,396 \text{ t C}$$

And the uncertainty =  $\sqrt{8^2 + 15^2} = \pm 17\%$ , or higher than either parameter.

### 5.2 COMBINING UNCERTAINTIES FOR ADDITION AND SUBTRACTION

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

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

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):

	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 =

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

In this case the total uncertainty is lower than either of that of the components.

Using this simple error propagation method is applicable to many of the calculations used in this FP 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 can 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.

Total benefits are calculated as:

**Annual TOTAL CO<sub>2</sub> benefit (t CO<sub>2</sub> yr<sup>-1</sup>)**

= Annual benefits from PEAT FOREST, or

= Annual benefits from FOREST, or

= Annual benefits from MANGROVE FOREST

**Total CO<sub>2</sub> benefit (t CO<sub>2</sub>)** =  $\sum$ Yearly Total CO<sub>2</sub> benefits (t CO<sub>2</sub> yr<sup>-1</sup>)

### 6.1. PEAT FOREST EQUATIONS

**Annual benefits from Peat Forest (t CO<sub>2</sub> yr<sup>-1</sup>)**

= avoided deforestation emissions + foregone sequestration + avoided illegal logging emissions + avoided fire emissions – community offtake emissions

**Total Forest CO<sub>2</sub> benefit (t CO<sub>2</sub>)**

$$= \sum \text{Yearly Forest CO}_2 \text{ benefits (t CO}_2 \text{ yr}^{-1})$$

**6.1.1 AVOIDED DEFORESTATION**Deforestation emissions (t CO<sub>2</sub> yr<sup>-1</sup>)

$$= \text{Avoided Deforestation Emissions Trees} + \text{Avoided Deforestation Emissions Soil}$$

**6.1.1.1 AVOIDED DEFORESTATION EMISSIONS FROM TREES**Avoided Deforestation Emissions Trees (t CO<sub>2</sub> yr<sup>-1</sup>)

$$= \text{Area of avoided deforestation in year } n \text{ (ha)} \times \text{Tree Carbon Stock (t C ha}^{-1}) \times (44/12)$$

Area of avoided deforestation in year n (ha)

$$= \text{Forest Area at end of year } n-1 \text{ (ha)} \times \text{Deforestation Rate (\% yr}^{-1}) \times (\text{fraction effectiveness in avoiding deforestation and/or illegal logging})$$

Forest Area at end of year n (ha)

$$= \text{Forest Area in year } 0 \text{ (ha)} - \text{Actual Area Deforested in Year } 1 \text{ (ha)} - \text{Actual Area Deforested in Year } 2 \text{ (ha)} - \dots - \text{Actual Area Deforested in Year } n \text{ (ha)}$$

Actual Area Deforested in Year n (ha)

$$= \text{Forest Area at end of year } n-1 \text{ (ha)} \times \text{Deforestation Rate (\% yr}^{-1}) \times (1 - \text{fraction effectiveness in avoiding deforestation and/or illegal logging})$$

Deforestation rate (% yr<sup>-1</sup>)

$$= \text{Deforestation Rate}_{\text{Pre}} \text{ (\% yr}^{-1}) - \text{Deforestation Rate}_{\text{Post}} \text{ (\% yr}^{-1})$$

*Note: If a user enters a value for Deforestation Rate<sub>post</sub> in 'Advanced Inputs' then the '% effectiveness in avoiding deforestation and/or illegal logging' term is set to 100% in the equations above. The calculated 'effectiveness in avoiding deforestation and/or illegal logging' is still multiplied by the illegal logging emissions term. See Effectiveness Guide guidance document for more details.*

**6.1.1.2 DEFORESTATION EMISSIONS FROM SOIL**Avoided Deforestation Emissions Soil (t CO<sub>2</sub> yr<sup>-1</sup>)

$$= \text{Avoided Deforestation Emissions Mineral} + \text{Avoided Deforestation Emissions Peat}$$

Avoided Deforestation Emissions Peat (tCO<sub>2</sub> yr<sup>-1</sup>)

$$= \text{Avoided Deforestation Emissions Peat Drainage} + \text{Avoided Deforestation Emissions Peat}$$

Burn<sub>initial</sub>Avoided Deforestation Emissions Peat Drainage (tCO<sub>2</sub> yr<sup>-1</sup>)

$$= \sum \text{Area deforested in year } n_{1\dots n} \text{ (ha)} \times \% \text{ Peat} \times \text{EF}_{\text{PeatDrainage}} \text{ (t CO}_2 \text{ cm}^{-1} \text{ ha}^{-1} \text{ yr}^{-1}) \times \text{DrainageDepth (m)} \times 100$$

Where:

$$\text{EF}_{\text{drainagepeat}} = 0.72 \text{ t CO}_2 \text{ cm}^{-1} \text{ ha}^{-1} \text{ yr}^{-1} \text{ (see discussion on this above)}$$

100 = conversion of emissions factor from per cm to per m

*Note: Peat soils are assumed to keep emitting due to drainage as their drainage depth is likely to be maintained to allow the agriculture or forestry to continue.*

Avoided Deforestation Emissions Peat  $\text{Burn}_{\text{initial}}$

$$= \text{Area of avoided deforestation in year } n \text{ (ha)} \times \% \text{ Peat} \times \text{Burn Depth Initial (m)} \times \text{Peat Carbon Density (t C m}^{-3}) \times 10,000 \times 44/12$$

Where:

$$\text{Peat Carbon Density} = 0.06 \text{ t C m}^{-3}$$

10,000 = conversion from emissions in 1 m<sup>2</sup> to 1 ha

For projects that are partially or fully located on mineral soils, changes in soil carbon stocks on mineral soils converted to cropland were calculated based on Section 5.3.3.4 of the 2006 IPCC Guidelines on Agriculture, Forestry and Other Land Use. The basic equation is to calculate the difference in carbon stocks in the soil before and after agricultural conversion, and to divide this value by an assumed time period over which the change is forecasted to occur. This time period is assumed to be 20 years.

$$\text{Avoided Deforestation Emissions Mineral (tCO}_2 \text{ yr}^{-1}) = \text{Area of avoided deforestation in year } n \text{ (ha)} \times \text{change in mineral soil stocks} \times (1 - \% \text{ peat}) \times 44/12$$

$$\text{Change in mineral soil stocks} = (\text{SOC}_0 - \text{SOC}_D) / D$$

$$\text{SOC}_D = \text{SOC}_0 * F_{\text{LU}} * F_{\text{MG}} * F_{\text{I}}$$

Where:

$\text{SOC}_0$  = initial soil organic carbon; t C ha<sup>-1</sup> to 30 cm depth

$\text{SOC}_D$  = soil organic carbon at the default time to reach equilibrium, assumed to be 20 yr; t C ha<sup>-1</sup> to 30 cm depth

D = Time dependence of stock change factors, which is the default time period for transition to a new equilibrium SOC value assumed to be 20 years

$F_{\text{LU}}$  = stock change factor for land-use systems or sub-system for a particular land-use, dimensionless

$F_{\text{MG}}$  = stock change factor for management regime, dimensionless

$F_{\text{I}}$  = stock change factor for input of organic matter, dimensionless

**6.1.2 FOREGONE SEQUESTRATION**

Foregone sequestration

$$= \sum \text{Area of avoided deforestation in year } n_{(1,\dots,20)} \text{ (ha)} \times \text{Forest Growth rate } < 20 \text{ years (tC ha}^{-1} \text{ yr}^{-1}) \times (44/12) + \sum \text{Area of avoided deforestation in year } n_{(20,\dots,30)} \text{ (ha)} \times \text{Forest Growth rate } > 20 \text{ years (tC ha}^{-1} \text{ yr}^{-1}) \times (44/12)$$

**6.1.3 AVOIDED FIRE**

CO<sub>2</sub> emissions from fire are calculated as the sum of emissions from biomass burning and, for projects that take place on peat, from peat burning.

Avoided Fire Emissions<sub>n</sub> (tCO<sub>2</sub> yr<sup>-1</sup>)

= (Biomass Burning<sub>n</sub> + Peat Biomass Burning<sub>n</sub>) × % effectiveness in avoiding deforestation, fire and/or illegal logging

Avoided Biomass Burning<sub>n</sub> (tCO<sub>2</sub> yr<sup>-1</sup>)

$$= \text{Forest in year } n \text{ (ha)} \times (\text{Fire Incidence Rate} \times \text{Tree Carbon Stock (tC ha}^{-1}) \times (1/0.47) \times \text{Cf} \times \text{EF}) \times 10^{-3}$$

Where:

Cf = Combustion factor (0.36)

EF = Fire emissions factor (1580 g CO<sub>2</sub> per kg of dry matter burnt)

Avoided Peat Biomass Burning<sub>n</sub> (tCO<sub>2</sub> yr<sup>-1</sup>)

$$= \text{Forest Area at end of year } n \text{ (ha)} \times \text{Fire Incidence Rate} \times \% \text{ Peat} \times \text{Burn Depth Annual (m)} \times \text{Peat Carbon Density (t C m}^{-3}) \times 10,000 \times 44/12$$

Where :

Peat Carbon Density = 0.06 t C m<sup>-3</sup>

10,000 = conversion from m<sup>2</sup> to ha

**6.1.4 AVOIDED ILLEGAL LOGGING**

CO<sub>2</sub> emissions from illegal logging and community logging are both calculated as the sum of emissions from timber extraction and from incidental damage to the surrounding forest. The main difference is how these values are used in the overarching equation – if the emissions are avoided because the project is stopping illegal logging, then the project is credited with emissions reductions. If the emissions occur as part of a larger forest protection project with a small allowable additional cut for the local communities, then the project must take a debit for these CO<sub>2</sub> emissions that occur.

Avoided Illegal logging emissions (tCO<sub>2</sub> yr<sup>-1</sup>) = (TimberTree<sub>illegal</sub> + Incidental Damage<sub>illegal</sub>) × 44/12 × % effectiveness in avoiding deforestation and/or illegal logging

$$\text{TimberTree}_{\text{illegal}_n} = \text{Forest Area at project start (ha)} \times \text{Illegal Logging Rate} \times \text{ELE}$$

$$\text{ELE} = (0.4924 \times \text{Wood Density}) - 0.0158$$

Where:

TimberTree <sub>illegal_n</sub>	= carbon in extracted timber from illegal logging in year n (t C)
Illegal logging rate	= volume timber over bark extracted illegally each year (m <sup>3</sup> ha <sup>-1</sup> yr <sup>-1</sup> )
ELE	= Extracted Log Emissions (t C m <sup>-3</sup> extracted)
Wood Density	= Wood Density (t m <sup>-3</sup> )

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 (Illegal logging rate) and the project area. 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.

$$\text{IncidentalDamage}_{\text{illegal}} = \text{LDF} \times \text{Illegal logging rate}$$

$$\text{LDF} = -0.0039(\text{Tree Carbon Stock}) + 1.7817$$

Where:

LDF = Logging Damage Factor, the carbon emitted due to damage to surrounding trees per m<sup>3</sup> of timber extracted.

Tree Carbon Stock = The carbon stored in the trees (above and below ground) (t C ha<sup>-1</sup>).

Users can adjust the Tree Carbon Stock value under advanced inputs

### 6.1.5 COMMUNITY OFFTAKE

$$\text{Community Offtake (tCO}_2 \text{ yr}^{-1}) = (\text{TimberTree}_{\text{Comm}} + \text{Incidental Damage}_{\text{Comm}}) \times 44/12$$

$$\text{TimberTree}_{\text{community}} = \text{Community Area} \times \text{Community Offtake} \times \text{ELE}$$

$$\text{ELE} = (0.4924 \times \text{Wood Density}) - 0.0158$$

Where:

TimberTree <sub>illegal</sub>	= carbon in extracted timber from illegal logging (t C)
Community Area	= The community logging area (ha)

Community Offtake = volume timber over bark extracted by communities each year ( $\text{m}^3 \text{ha}^{-1} \text{yr}^{-1}$ )

ELE = Extracted Log Emissions ( $\text{t C m}^{-3}$  extracted)

Wood Density = Wood Density ( $\text{t m}^{-3}$ )

Users can adjust the wood density value under advanced inputs.

$\text{IncidentalDamage}_{\text{illegal}} = \text{LDF} \times \text{Community offtake}$

$\text{LDF} = -0.0039(\text{Tree Carbon Stock}) + 1.7817$

Where:

LDF = Logging Damage Factor, the carbon emitted due to damage to surrounding trees per  $\text{m}^3$  of timber extracted.

Tree Carbon Stock = The carbon stored in the trees (above and below ground) ( $\text{t C ha}^{-1}$ ).

Users can adjust the Tree Carbon Stock value under advanced inputs

## 6.2. FOREST EQUATIONS

The equations when 'Forest' is selected are exactly the same as when Peat Forest is selected but '% peat' is set to zero meaning the soils are 100% mineral and there are no peat-related emissions.

## 6.3. MANGROVE FOREST EQUATIONS

**Annual benefit from Mangrove Forest ( $\text{t CO}_2 \text{yr}^{-1}$ )**

= mangrove avoided deforestation emissions + foregone sequestration in mangroves

**Total Mangrove Forest  $\text{CO}_2$  benefit ( $\text{t CO}_2$ )**

= SUM of ALL Yearly Mangrove Forest  $\text{CO}_2$  benefits ( $\text{t CO}_2 \text{yr}^{-1}$ )

### 6.3.1 DEFORESTATION

Mangrove deforestation emissions ( $\text{tCO}_2 \text{yr}^{-1}$ )

= Area of avoided mangrove deforestation in year n (ha)  $\times$  Mangrove Carbon Stock ( $\text{tC ha}^{-1}$ )  $\times$  (44/12)

Area of avoided mangrove deforestation in year n (ha)

= Mangrove Forest Area at end of year n-1 (ha)  $\times$  Mangrove Deforestation Rate ( $\text{ha yr}^{-1}$ )  $\times$  (1 - % effectiveness in avoiding deforestation and/or illegal logging)

Mangrove Forest Area at end of year n (ha)

= Mangrove Forest Area in year 0 (ha) - Actual Mangrove Area Deforested in Year 1 (ha) - Actual Mangrove Area Deforested in Year 2 (ha) - ... Actual Mangrove Area Deforested in Year n (ha)

Actual Mangrove Area Deforested in Year n (ha)

= Mangrove Forest Area at end of year n-1 (ha) × Mangrove Deforestation Rate (ha yr<sup>-1</sup>) × (effectiveness in avoiding deforestation and/or illegal logging)

Deforestation rate (ha yr<sup>-1</sup>)

= Mangrove Deforestation Rate<sub>Pre</sub> (ha yr<sup>-1</sup>) - Mangrove Deforestation Rate<sub>Post</sub> (ha yr<sup>-1</sup>)

*Note: If a user enters a value for Mangrove Deforestation Rate<sub>post</sub> in 'Advanced Inputs' then the % effectiveness in avoiding deforestation is set to 100% in the equations above. See Effectiveness Guide guidance document for more details.*

### 6.3.2 FOREGONE SEQUESTRATION

Removals from foregone sequestration of mangroves

=  $\sum$  Area of avoided deforestation in year n<sub>1,...,20</sub> (ha) × Mangrove Growth Rate (tC ha<sup>-1</sup> yr<sup>-1</sup>) × (44/12)

## 6.4. HYPOTHETICAL EXAMPLE

A hypothetic Forest Protection project activity of reducing deforestation on 10,000 hectares in the Democratic Republic of Congo is given as an example here. First, users have to select the geographic location of the project, which in this hypothetical example will take place in the Bandundu Province, DRC.

After entering the total area of the FP project activity (10,000 ha), the user has to respond to a simple questionnaire to estimate the effectiveness rating of the FP project activity. The result of this questionnaire was that the project was likely to be 60% effective in avoiding deforestation when operating at its maximum potential. The project is in its second year, and is likely to need three years to be fully effective. These values were entered into the FP tool.

The user must then specify whether the project protects against fire, deforestation, or illegal logging. As described above, the ACC's default values only address protection against deforestation, which was chosen for this example.

If no default values are overridden under Advanced Inputs, the carbon benefits from protection against deforestation for the focal year are calculated as follows (assuming no community offtake and no peat soil):

= (60%/100) \* (44/12) \* {(area deforested \* tree carbon) + (area deforested \* [soil carbon – (soil carbon \* F<sub>LU</sub> \* F<sub>MG</sub> \* F<sub>I</sub>)]/20) + (area deforested \* forest growth rate)}

Where:

Area deforested = Default deforestation rate \* forest area = 0.65% \* 10,000 = 64.5

Tree Carbon: 107 t C ha<sup>-1</sup>

Soil Carbon: 35.9 t C ha<sup>-1</sup>

F<sub>LU</sub>: 0.48

F<sub>MG</sub>: 1

F<sub>i</sub>: 1

Growth rate: 1.88 t C ha<sup>-1</sup> yr<sup>-1</sup>

Because the percentage peat is zero for this project area, carbon benefits are calculated as:

$$= 60\% * (44/12) * \{(64.5 * 107) + (64.5 * [(35.9 - (35.9 * 0.48 * 1 * 1)]/20) + (64.5 * 1.88)\}$$

$$= \mathbf{15,583 \text{ t CO}_2\text{e}}$$

In this hypothetical example, the FP project activity that is 60% effective in protecting 10,000 ha of native forests against deforestation in Bandundu, DRC, has resulted in a carbon benefit of approximately **15,583 t CO<sub>2</sub>e** during the first year.

## 7. OVERRIDING DEFAULT DATA

Under Required Inputs, the user is given an option to change default parameters by entering project-specific data. The following are the optional inputs for 'Advanced Inputs' under the Forest Protection calculator:

### **Forest Characteristics**

Forest carbon stock (above and below ground combined)

### **Deforestation**

Deforestation rate before intervention

Deforestation rate after intervention

Annual forest growth (< 20 years old)

Annual forest growth (> 20 years old)

Soil carbon stock at time zero

### **Community logging**

Community forestry area

Annual community wood extraction rates

### **Peat Specific**

Peat swamp percentage

Peat carbon density

Initial burn depth

Average depth of peat drained

Average depth of peat burned

**Mangroves**

Mangrove deforestation rate before intervention

Mangrove deforestation rate after intervention

Mangrove growth

Mangrove carbon stocks

**Illegal logging**

Annual illegal logging rate before intervention

Extraction rate

Wood density

**Fire**

Annual fire frequency before intervention

## 8. REFERENCES

- Agus, F., Henson, I., Sahardjo, B., Harris, N., van Noordwijk, M. and Timothy J. Killeen. 2013. Review of emission factors for assessment of CO<sub>2</sub> emission from land use change to oil palm in Southeast Asia. Reports from the Technical Panels of the 2nd Greenhouse Gas Working Group of the Roundtable on Sustainable Palm Oil (RSPO).
- Brown, S. 1997. Estimating Biomass and Biomass Change of Tropical Forests: A Primer. UN FAO Forestry Paper 134, Rome. 55 pp. FAO. 2007. The World's Mangroves 1980-2005. FAO Forestry Paper 153, Rome.
- Couwenberg, J., R. Dommain and H. Joosten. 2009. Greenhouse gas fluxes from tropical peatlands in south-east Asia. *Global Change Biology*, in press. DOI: 10.1111/j.1365-2486.2009.02016.x
- Fatoyinbo, T., Biospheric Sciences Laboratory at NASA Goddard Space Flight Center. Personal Communication, August 2012 – May 2013.
- Fatoyinbo, T and M. Simard. 2012. Height and biomass of mangroves in Africa from ICESat/GLAS and SRTM. *International Journal of Remote Sensing*.
- Gallaun H., Zanchi G., Nabuurs G.J., Hengeveld G., Schardt M., and Verkerk P.J. 2010. EU-wide maps of growing stock and above-ground biomass in forests based on remote sensing and field measurements. *Forest Ecology and Management*, Vol. 260, No. 3, pp. 252-261.
- GOFC-GOLD, 2013, A sourcebook of methods and procedures for monitoring and reporting anthropogenic greenhouse gas emissions and removals associated with deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation. GOFC-GOLD Report version COPI9-2, (GOFC-GOLD Land Cover Project Office, Wageningen University, The Netherlands).
- Hooijer, A., Page, S. E., Jauhiainen, J., Lee, W. A., Lu, X.X, Idris, A., & Anshari, G. 2012. Subsidence and carbon loss in drained tropical peat soils. *Biogeosciences*, 9, 1053–1071.
- Hooijer, A., M. Silvius, H. Wosten, and S. Page. 2006. PEAT-CO<sub>2</sub>, Assessment of CO<sub>2</sub> emissions from drained peatlands in SE Asia. Delft Hydraulics report Q3943.
- Houghton, R.A., D. Butman, A.G. Bunn, O.N. Krankina, P. Schlesinger and T.A. Stone. 2007. Mapping Russian forest biomass with data from satellites and forest inventories. *Environmental Research Letters* 2: 045032.
- Hutchison, J., Manica, A., Swetnam, R., Balmford, A. and Spalding, M. (2014), Predicting Global Patterns in Mangrove Forest Biomass. *Conservation Letters*, 7: 233–240.
- IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, 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/vol1.htm>
- Muraleedharan, T.R., M. Radojevic, A. Waugh, and A. Caruana. 2000. Emissions from the combustion of peat: an experimental study. *Atmospheric Environment* 34: 3033-3035.
- Page, S.E., Siegert, F, Rieley J.O., Boehm, H.V., Jaya, A. & Limin, S. 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature*, 420,61-65.
- Page, S.E., Banks, C.J. and Rieley, J.O. In Review. Extent and global significance of tropical peat carbon pools. *Global Change Biology*
- Pearson, T.R.H., S. Brown, and F.M. Casarim. 2014. Carbon emissions from tropical forest degradation caused by logging. *Environ. Res. Lett* 9 034017 (11 pp); doi:10.1088/1748-9326/9/3/034017
- Piao, S., J. Fang, B. Zhu, K. Tan. 2005. Forest biomass carbon stocks in China over the past 2 decades: estimation based on integrated inventory and satellite data. *Journal of Geophysical Research* 110: G01006.

- Ruesch, A. and H.K. Gibbs. 2008. New IPCC Tier-I Global Biomass Carbon Map for the Year 2000. Available online from the Carbon Dioxide Information Analysis Center [<http://cdiac.ornl.gov>], Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.
- Saatchi, SS. In preparation. High resolution spatial patterns of forest carbon stocks in pan tropical regions from fusion of global multi-sensor data fusion. Developed by Jet Propulsion Laboratory, UCLA Institute of Environment, Winrock International, Applied Geosolution. Unpublished dataset.
- Saatchi, S. S., N. L. Harris, S. Brown, M. Lefsky, E. T. A. Mitchard, W. Salas, B. R. Zutta, W. Buermann, S. L. Lewis, S. Hagen, S. Petrova, L. White, M. Silman, and A. Morel. 2011. Benchmark map of forest carbon stocks in tropical regions across three continents. PNAS 108 (24):9899-9904. [www.pnas.org/cgi/doi/10.1073/pnas.1019576108](http://www.pnas.org/cgi/doi/10.1073/pnas.1019576108)
- Tansey, K., Grégoire, J.-M., Defourny, P., Leigh, R., Pekel, J.-F., van Bogaert, E., and Bartholomé, E. 2008. A new, global, multi-annual (2000–2007) burnt area product at 1 km resolution, Geophys. Res. Lett., 35, L01401, DOI:10.1029/2007GL031567.
- Twilley, R.R., R.H. Chen. and T. Hargis. 1992. Carbon sinks in mangroves and their implications to carbon budget of tropical coastal ecosystems. Water, Air, and Soil Pollution 64:265-288.

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