Guyana Forestry Commission

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Forest Carbon Monitoring System: Emission Factors and their Uncertainties, Version 2

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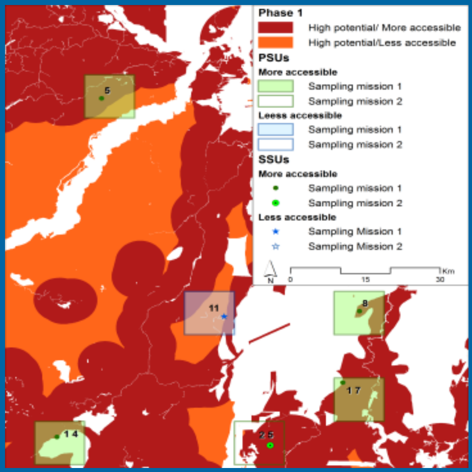

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1.0 BACKGROUND

The Monitoring, Reporting, and Verification System (MRVS) being developed by Guyana will allow it to determine greenhouse gas emissions and removals resulting from deforestation and forest degradation measured against business-as-usual (BAU) emissions. The Forest Carbon Monitoring System (FCMS) is a critical element of the MRVS as it provides details of the methods required to provide statistically robust estimates of the Emission Factors (EFs) –the EFs are used with activity data (AD) to estimate carbon emissions from changes in forest cover in Guyana.

This report explains the development of emission factors for Guyana: **the emissions and removals of greenhouse gases per unit of activity data,** based on the methods described in the sampling design and implementation plan—version 2 (Brown et al. 2014), the Conversion Factor Handbook: Version 2 (Goslee et al 2013), and the Excel Workbook for Estimating Historic Emissions (Brown et al. 2014). Emission factors for areas of High Potential for Change (HPfC) and Medium Potential for Change (MPfC), Phases 1 and 2, have been finalized.

The estimation of total greenhouse gas emissions and removals is the combination of both activity data and emissions factors. Activity data refer to the extent of deforestation and degradation and are obtained through remote sensing and statistical data on timber production. Comprehensive annual reports on monitoring of Guyana's forests by remote sensing have been produced by GFC and Pöyry (2011) and Indufor (2012, 2013).

2.0 CALCULATING EMISSION FACTORS

A simple Excel workbook has been developed (Brown et al, 2014a) to show how the EFs are calculated along with their corresponding uncertainties. Emission factors were calculated separately for each specific driver of deforestation and/or degradation and for each relevant stratum. They are based on the field data collection from the sampling design plan and other factors from the IPCC (2006). Data have been collected in four initial strata:

- High Potential for Change, More Accessible (HPfC MA)
- High Potential for Change, Less Accessible (HPfC LA)
- Medium Potential for Change, More Accessible (MPfC MA)
- Medium Potential for Change, Less Accessible (MPfC LA)

2.1 Deforestation

2.1.1 Carbon Stocks

Carbon stocks in the HPfC MA and HPfC LA strata are significantly different (P=0.0002), so these two strata were maintained, with emission factors developed for each. Carbon stocks in the MPfC MA and MPfC LA are not significantly different from one another (P=0.90). Therefore, these two strata were combined into one MPfC stratum for the development of EFS. Carbon stock data for these three strata are shown in Table 1. Data have not yet been collected in the Low Potential for Change areas[1]; carbon stocks from the MPfC stratum are used to develop emission factors for the LPfC stratum and estimate emissions.

Table 1. Carbon stocks by pool for the three strata in Guyana's FCMS.

Stratum	AG Tree (t C/ha)	BG Tree (t C/ha)	Saplings (t C/ha)	Standing Dead Wood (t C/ha)	Lying Dead Wood (tC/ha)	Litter (tC/ha)	**Sum Carbon Pools (t C/ha)**	number of plots	95% CI as a % of mean
HPfC MA	193.6	45.5	4.2	2.0	11.1	3.3	259.8	26	7.8%
HPfC LA	267.6	62.9	4.1	2.0	8.8	5.6	351.0	16	10.1%
MPfC	231.1	54.3	3.5	2.3	5.6	3.2	300.0	24	12.1%

2.1.2 Method for Estimating Emission Factors

The drivers of deforestation in Guyana –mining, agriculture, and infrastructure—are assumed to result in the complete removal of all vegetation, and do not entail the subsequent use of any timber going into long term wood products[2]. The emission factor for deforestation for the aforementioned drivers was calculated as the sum of all carbon stocks from all live and dead biomass pools and the change in stock for the soil carbon pool.

$$EF_{deforestaton} = \{C_{AGB} + C_{BGB} + C_{DW} + C_{LT} + C_{sap} + [C_{soil} - (C_{soil} \times F_{LU} \times F_{MG} \times F_{I})]\} *44/12$$

Where:

$EF_{deforestation}$ = Emission factor for deforestation; t CO_2 ha^{-1}

C_{AGB} = Carbon stock in aboveground biomass pool; t C ha^{-1}

C_{BGB} = Carbon stock in belowground biomass pool; t C ha^{-1}

C_{DW} = Carbon stock in dead wood pools (standing and lying); t C ha^{-1}

C_{LT} = Carbon stock in the litter pool; t C ha^{-1}

C_{sap} = Carbon stock in saplings; t C ha^{-1}

C_{soil} = Carbon stock in soil organic matter pool (to 30 cm); t C ha^{-1}

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[1] Because these areas are unlikely to experience much change in the near future, it is not recommended that data be collected in the LPfC stratum until higher rates of change are observed (>50 yr or so).

[2] It is likely that any commercial timber available when constructing forest roads is extracted beforehand, and that this will end up in a variety of wood products. However the amount extracted is unknown and the amount going into long term products is small depending on final product (from 1-10% of the timber logs). This could be incorporated into the EF for logging roads when such data are available.

F_{LU} = Stock change factor for land-use systems for a particular land-use, dimensionless (Table 2)

F_{MG} = Stock change factor for management regime, dimensionless (See Table 2)

F_I = Stock change factor for input of organic matter, dimensionless (See Table 2)

Soil carbon stocks are impacted differently by different drivers, and the change in carbon stocks in the top 30 cm of soil is calculated as the difference between the soil carbon stocks before conversion and the soil carbon stocks after conversion. Soil carbon stocks after conversion were estimated based on land use, management, and input factors as derived from IPCC (2006)[3]. For simplicity in accounting, we assume the full emission of soil carbon in the year of clearing, rather than spreading the emissions over 20 years (the default time period suggested by IPCC 2006). The changes in soil carbon by each driver, estimated from the emission factor equation $[C_{soil} - (C_{soil} \times F_{LU} \times F_{MG} \times F_I)]$, are given in Table 2. This equation estimates the soil C stock at year 20 by multiplying the initial C stock by each of the soil factors that account for how the soil is tilled, what sort of management is applied, and quantity and type of inputs applied. The estimates of the C stock after 20 years of use are based on the application of each factor to the original soil C stock. Thus the change in C stock in the soil by each driver is the initial C stock minus the C stock at year 20.

We assumed that fire did not result in changes to soil carbon stocks. Fires in Guyana do not reach the intensity or duration necessary to impact soil carbon. For these drivers, therefore, soil carbon is not included in the calculation of the emission factor.

[3] IPCC (2006). Guidelines for National Greenhouse Gas Inventories. Volume 4, Agriculture, Forestry and Other Land Use.

Table 2. Values for stock change factors for soil carbon by driver based on IPCC, 2006, and final change in soil carbon as calculated for Guyana.

Stratum/driver	C stock (t C/ha)	95% CI as % of the mean	F_{LU}	F_{MG}	F_I	C stock at 20 yr (t C/ha)	Change in Soil C (t C/ha)
HPfC MA	99.3	21.6%					
Conversion to permanent agriculture			0.48	1.00	1.00	47.7	**51.6**
Conversion to mining or infrastructure			0.82	1.00	0.92	74.9	**24.4**
HPfC LA	80.3	17.4%					
Conversion to permanent agriculture			0.48	1.00	1.00	38.5	**41.8**
Conversion to mining or infrastructure			0.82	1.00	0.92	60.6	**19.7**
MPfC	96.5	21.0%					
Conversion to permanent agriculture			0.48	1.00	1.00	49.0	**53.1**
Conversion to mining or infrastructure			0.82	1.00	0.92	77.0	**25.1**

The emissions from fire based on Eq. 2.27 in the IPCC 2006 GL, are estimated as follows:

$$L_{fire} = M_B * C_f * G_{ef} * 10^{-3}$$

Where:

L_{fire} = amount of greenhouse gas emissions from fire, t $ha^{-1}$of each GHG ha^{-1} e.g., CO_2, CH_4, N_2O

M_B = mass of fuel available for combustion, t ha^{-1}. This includes biomass in Guyana's selected pools of aboveground biomass, litter and dead wood (belowground biomass is excluded as this is unlikely to burn) for the more and less accessible zones.

C_f = combustion factor (proportion of pre-fire biomass that burns; from Table 2.6 IPCC 2006 GL), dimensionless; default value for tropical moist forest is 0.50 (assumed conservatively to be more intense) based mostly on data from fire experiments in Brazil forest areas.

G_{ef} = emission factor, g kg-1 dry matter burnt (from Table 2.5 IPCC 2006 GL) for each GHG as follows: 1580 for CO_2, 6.8 for CH_4, and 0.20 for N_2O

These are converted to carbon dioxide equivalents by multiplying by the appropriate global warming potential factor (21 for methane and 310 for nitrous oxide). The combustion factor of 0.5 assumes only 50% of the biomass is burned and the rest of the dead mass is left behind. We assume that this represents a committed emission and thus add the emissions from the non-combusted biomass to the emission factor.

2.1.3 Emission Factors for Deforestation

Emission Factors for deforestation in all strata are shown in Table 3.

Table 3. Emission Factors for drivers of deforestation in areas of high (HPfC) and medium (MPfC) potential for change. These EFs assume all the carbon in vegetation is emitted to the atmosphere at the time of the event.

Stratum	Drivers	Biomass carbon (t C ha^{-1})	Change in soil carbon (t C ha^{-1})	EF (t CO_2e ha^{-1})
HPfC MA	Forestry infrastructure (roads and decks)	259.8	24.4	1,042.0
	Agriculture	259.8	51.6	1,141.9
	Mining (medium and large scale)	259.8	24.4	1,042.0
	Mining infrastructure	259.8	24.4	1,042.0
	Infrastructure (other roads)	259.8	24.4	1,0420
	Fire-Biomass burning	NA	NA	775.4
HPfC LA	Forestry infrastructure (roads and decks)	351.0	19.7	1,359.5
	Agriculture	351.0	41.8	1,440.2
	Mining (medium and large scale)	351.0	19.7	1,359.5
	Mining infrastructure	351.0	19.7	1,359.2
	Infrastructure (other roads)	351.0	19.7	1,359.5
	Fire-Biomass burning	NA	NA	1,042.6
MPfC (and LPfC)	Forestry infrastructure (roads and decks)	300.0	23.7	1,186.9
	Agriculture	300.0	50.2	1,284.0
	Mining (medium and large scale)	300.0	23.7	1,186.9
	Mining infrastructure	300.0	23.7	1,186.9
	Infrastructure (other roads)	300.0	23.7	1,186.9
	Fire-Biomass burning	NA	NA	889.0

2.2 Degradation

The drivers addressed in this section include only selective logging; factors for shifting cultivation, fire, and degradation on the edges of deforestation from mines and roads are not included at this time. As emissions from deforestation due to fire are insignificant it is expected that emissions from degradation due to fire will be even more insignificant. It is also unclear if the areal extent of degradation by fire can be quantified. At this time it is not recommended that efforts be taken to quantify such factors.

2.2.1 Method for Estimating Emission Factors for Selective logging

The majority of degradation in Guyana is the result of selective logging, both legal and illegal. Selective logging is also the driver that has the most well-established methods for quantifying emissions. There are a number of emission factors related to selective logging[4]: a logging damage factor (LDF), a logging infrastructure factor (LIF), and a factor for the proportion of carbon stored in long-term wood products (C_{LTP}).

The total gross emissions for selective logging are calculated as follows:

$$Emissions = \{([V_{Total} * WD * CF) * (1 - C_{LTP})] + (LDF * V_{Total}) + (LIF * Length_{Skids})\} * 44/12$$

Where:

Emissions	gross greenhouse gas emissions resulting from timber harvest (t CO_2/yr)
V_{Total}	total true volume of logs, over bark, produced (m^3/yr)
WD	wood density of commercially harvested timber (t /m^3, from logging plots)
CF	carbon dioxide fraction of biomass (=0.50 t C/t dry mass from IPCC)
LDF	logging damage factor—dead biomass carbon left behind in gap from felled tree and incidental damage (t C/m^3 extracted, from field data for logging plots)
LIF	logging infrastructure factor—dead biomass carbon caused by construction of skid trails infrastructure to extract the timber (t CO_2/km, from field data on biomass plots and measurements of width of a sample of skid trails)
$Length_{Skids}$	total length of skid trails constructed to extract timber (km, from reported lengths as part of planning process reported to GFC; part of activity data)
C_{LTP}	proportion carbon stored in long-term wood product (dimensionless)
44/12	conversion factor for t C to t CO2 equivalent

The **logging damage factor (LDF)** is the total carbon emissions per volume of timber extracted, t CO_2/m^3. It accounts for emissions in logging gaps as a result of dead biomass carbon left behind from both the felled tree itself and incidental damage to surrounding trees, and is calculated as follows based on all the data from the logging plots:

$$LDF = \left[\sum_{n=i} \frac{(C_{FT} - C_{EXT}) + ID}{V_{EXT}}\right]$$

Where:

n = total number of plots

C_{FT} = felled tree carbon (t C/plot)

[4] Pearson, TRH, S Brown, and FM 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

C_{EXT} = carbon extracted in the timber (t C/plot)

ID = incidental damage to non-felled trees in logging gap (t C/plot)

V_{EXT} = volume of timber extracted (m^3/plot)

The **logging infrastructure factor (LIF)** is the total C emissions per length of skid trail, t C/km. Common practice in Guyana is to avoid killing timber trees in the creation of the skid trail, so the emissions are calculated accordingly, accounting only for those trees that are less than the legal allowable minimum diameter of harvestable trees, 35 cm dbh.

$$LIF = \{A_{ST} * C_{ST}\}$$

Where:

A_{ST} = skid trail area per km (ha/km)

= (average width of skid trails (m) * 1,000 m/km)/10^4 m^2/ha

C_{ST} = mean carbon stock of trees < legal allowable minimum diameter in skid trails (t C/ha)

The **proportion of carbon stored in long-term wood products (C_{LTP})** is dimensionless, and is calculated based on wood product class following the Winjum et al. 1997 method.

$$C_{LTP,i} = (1 - WW_i) * (1 - SLF_i) * (1 - OF_i)$$

Where:

i = wood product classes of sawnwood, woodbase panels and other industrial roundwood

WW_i = fraction of biomass effectively emitted to the atmosphere during production of wood product *i* (wood waste)

SLF_i – fraction of wood products that will be emitted to the atmosphere within 5 years of production of product *i*

OF_i – fraction of wood products that will be emitted to the atmosphere between 5 and 100 years after production of product *i*

Table 4 gives the values of the fractions used to estimate C_{LTP} in this analysis.

Table 4. Fraction of wood products emitted to the atmosphere during processing and use (from GFC data for WW and Winjum et al. 1997 for SLF and OF).

Product class	WW	SLF	OF 100 yr
Sawnwood	0.5	0.2	0.84
Woodbase panels	0.5	0.1	0.97
Other industrial roundwood	0.5	0.3	0.99

Wood density (WD) of commercially harvested timber is derived from field data from logging plots, calculated as the weighted mean of the wood density values of the harvested timber trees.

2.2.2 Emission Factors for Selective Logging

The final emission factors are shown in Table 5.

Table 5. Emission Factors used for estimating total emissions for degradation due to timber harvest, in areas of high threat for conversion. LDF – logging damage factor; LIF – logging infrastructure damage factor, and C_{LTP} – fraction of a given product class that goes into long term storage.

Driver	Emission Factors	
	Unit	t CO_2
LDF	per m^3	3.85
Wood Density of timber harvested	per m^3	1.47
LIF (Skid Trails)	per km	171.84
C_{LTP}**		
Sawnwood	Fraction	0.06
Woodbase panels	Fraction	0.01
Other industrial roundwood	Fraction	0.00

The majority of **illegal logging** in Guyana is the result of legal concessions extracting more than the allowable cut specified by the Guyana Forestry Commission. As a result, no additional infrastructure, such as skid trails, are developed for illegal logging, and the methods of harvesting are the same as those for legal logging. In addition, the volume of logs harvested illegally is reported as a percentage of annual production of timber in Guyana. Therefore, the emission factors for illegal logging are the same are those described above for legal logging.

3.0 UNCERTAINTY

To assess overall uncertainty when emission sources are combined, the following equation is used for error propagation, as recommended by IPCC[5]:

$$U_E = \{\sqrt{((U_1 * E_1)^2 + (U_2 * E_2)^2 + \ldots\ldots(U_n * E_n)^2)}\}/(E_1 + E_2 + \ldots.E_n)$$

Where:

U_E = percentage uncertainty of the sum

U_n = percentage uncertainty associated with each source i

E_n = carbon stock estimate for source i

3.1 Deforestation

The error propagation approach recommended by IPCC was used to combine all of the biomass carbon pools and estimate uncertainty for each stratum. The uncertainty in the soil pool was calculated separately because emissions from soil are calculated separate from emissions from biomass. The uncertainty in fire emissions was not estimated given the very insignificant contribution to the total emissions (<0.2% of total emissions). The uncertainty factors for both biomass and soil are provided in Table 6, by stratum.

Table 6. Factors for calculation of uncertainty for deforestation EFs, by stratum

Pool	HPfC MA	HPfC LA	MPfC (ALL)	LPfC (ALL)
Uncertainty in biomass carbon pools	7.8%	10.1%	12.1%	12.1%
Uncertainty in soil	21.6%	17.4%	21.0%	21.0%

3.2 Degradation

Uncertainty for LDF is based on the confidence interval as a percent of the mean LDF across all logging plots as sampling showed no difference in LDF based on different extraction rates for concessions operating in various cutting cycles.

Uncertainty for LIF is based on the confidence interval of the mean skid trail width and the mean C stock of trees below the legal allowable minimum diameter from the more accessible biomass plots.

The uncertainty in wood products is unknown, and is assumed to be 50%.

The emission factors for each element of degradation are shown in Table 7. Because these are not combined into one emission factor, there is not a combined uncertainty. Rather, when emissions are calculated, there is one uncertainty value for total emissions, weighted by the contribution of each factor to the total emissions.

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[5] Based on Equation 5.2.2 in IPCC GPG, http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp5/Chp5_1_&_5_2_Uncertainties.pdf.

Table 7. Factors for calculation of uncertainty for degradation EFs.

Factor	Uncertainty
LDF	9.4%
Wood Density	1.0%
Skid trails	14.6%

3.3 Monte Carlo Methods

An alternative to the error propagation method recommended by IPCC 2006 for estimation of uncertainty is a Monte Carlo (MC) simulation. The MC approach is a method for iteratively evaluating a deterministic model using sets of random numbers from a given distribution for each parameter as inputs. Using this model it is possible to substitute a range of values for any factor with uncertainty, thereby creating a stochastic model. A Deterministic model yields the same results with each recalculation, while a stochastic model introduces probability and randomness so that the results are different with each recalculation. It is appropriate to use a deterministic model when the functions are complex or nonlinear, uncertainty is high, there are multiple sources of uncertainty, correlations exist between datasets, or distribution is not normal.

In the case of development of emission factors for Guyana, Monte Carlo may be appropriate because correlations will exist between various measured carbon pools and between estimates of carbon stocks developed at different points in time. Using MC rather than error propagation method improves estimates of uncertainty from a Tier 2 to a Tier 3 method. Conducting a Monte Carlo simulation requires the use of additional software or programming language not included in standard spreadsheet software such as Microsoft Excel.

An initial Monte Carlo run has been conducted for the biomass carbon stocks in both the more accessible and less accessible strata of the high potential for change area. Table 8 compares the results for these Monte Carlo runs with the uncertainty derived from simple error propagation. For each, Monte Carlo analysis results in a slightly higher uncertainty estimates. Although the overall uncertainty increased with use of the MC analysis, the 95% CI is within the targeted error (95% CI<15% of mean).

Table 8. Comparison of uncertainty estimates for biomass stocks using error propagation and Monte Carlo Analysis

Stratum	Uncertainty – 95% CI as % of mean	
	Error Propagation	Monte Carlo
High Potential for Change – More Accessible	7.8%	8.4%
High Potential for Change – Less Accessible	10.1%	14.3%

4.0 REFERENCES

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