Ghana's National Forest Reference Level

JANUARY 2017

NATIONAL REDD+ SECRETARIAT, FORESTRY COMMISSION

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LIST OF ACRONYMS

AFOLU	Agriculture Forestry and Land Use
CCU	Climate Change Unit
CERSGIS	Centre for Remote Sensing and Geographic Information Services
CF	Carbon Fund
COCOBOD	Ghana Cocoa Board
COP	Conference of Parties
EC	Energy Commission
EPA	Environmental Protection Agency
ERPA	Emission Reduction Programme Agreement
FC	Forestry Commission
FCPF	Forest Carbon Partnership Facility
FORIG	Forest Research Institute of Ghana
FRL	Forest Reference Level
FSD	Forest Services Division
GCFRP	Ghana Cocoa Forest REDD+ Programme
GFPS	Ghana Forest Plantation Strategy
GIS	Geographic Information System

HIA	Hotspot Intervention Area (for the GCFRP)
HFZ	High Forest Zone
IPCC	Intergovernmental Panel on Climate Change
MODIS	Moderate Resolution Imaging Spectro-radiometer
MRV	Measurement Reporting and Verification
MTS	Modified Taungya System
NCRC	Nature Conservation Research Centre
NFMS	National Forest Monitoring System
NFPDS	National Forest Plantation Development Strategy
QA	Quality Assurance
QC	Quality Control
REDD	Reducing Emissions from Deforestation and Forest Degradation
RMSC	Resource Management Support Centre
SOP	Standard Operating Procedures
T1	Tier 1
T2	Tier 2
T3	Tier 3
TIFs	Tree Information Forms

EXECUTIVE SUMMARY

This document presents the national forest reference level (FRL) for Ghana to the UNFCCC. Ghana's FRL will serve as the baseline for measuring emissions reductions from the implementation of activities targeted at reducing emissions from deforestation and forest degradation, whilst recognising the role of conservation, sustainable forest management and carbon stocks enhancement (REDD+) under a results-based payment framework. This document and accompanying materials offer detailed information on historical emissions from all included REDD+ activities, as well as methods applied and data sources used to derive estimates of emissions and removals.

Ghana's envisaged REDD+ programs outlined in the National REDD+ Strategy are represent an ambitious and genuine commitment to lowering emissions from the land use sector whilst achieving significant co-benefits such as poverty reduction and enhanced agricultural productivity. Through Ghana's ongoing partnership with the Forest Carbon Partnership Facility (FCPF), significant efforts have been made to finalise Ghana's first sub-national REDD+ programme, christened the Ghana Cocoa Forest REDD+ Programme (GCFRP). The GCFRP is targeted at the cocoa-forest mosaic landscape of Ghana's High Forest Zone with an objective of reducing emissions attributed to expansionist agricultural activities as well as other drivers of deforestation and forest degradation in the programme area. In accordance with UNFCCC guidelines, Ghana's REDD+ programs and FRL are being developed in a manner that is:

- *Transparent – comprehensive and clear documentation of methods and data*
- *Complete – all significant emission sources, pools, and gases are estimated and reported*
- *Accurate – estimates of emissions are accurate and include estimates of uncertainty that are within 95% confidence interval of <+/-15% of the mean total carbon stock of forests*
- *Consistent – Emissions during the historical time period have been estimated in a manner that is consistent and shall remain functionally consistent during the REDD+ Program. Methodologies and data are also consistent with guidance agreed by the COP.*

The steady expansion of Ghana's agricultural and industrial sectors has brought considerable economic growth, yet have come at an environmental cost. Having lost over 60% of its forest cover from 1950 to the turn of the last century (2.7 million hectares)[1], Ghana's deforestation rate has been approximately 3% per year (320,803 ha/year) since 2000. Recent years have also seen a marked increase in the deforestation rate. From 2013 to 2015, the annual deforestation rate in Ghana rose to 794,214 ha per annum.

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[1] FAO, 2010. Global Forest Resources Assessment. Main report. Available at http://www.fao.org/docrep/013/i1757e/i1757e.pdf

This high rate of deforestation in Ghana is of major national concern as forests provide many ecosystem services and functions that support the country's predominantly agrarian economy. Furthermore, Ghana is currently a net emitter of CO_2 emissions, and thus contributes to the global imbalance of greenhouse gases driving climate change. As such, Ghana has turned to REDD+ as a mechanism to address these challenges.

Ghana began its engagement in REDD+ in 2008 through the World Bank's Forest Carbon Partnership Facility (FCPF). In 2016, it submitted a draft Emission Reduction Program Document (ER-PD) for the sub-national Ghana Cocoa Forest REDD+ Programme (GCFRP), which is concentrated in the High Forest Zone (HFZ). As is fully described in this document, the National FRL was developed based on work completed for the draft ER-PD. The national FRL is therefore congruent and methodologically consistent with the sub-national FRL. The methodologies applied are also consistent with UNFCCC guidelines and the FCPF Methodological Framework.

The key components of Ghana's FRL are as follows:

- Activities covered are **deforestation, forest degradation from legal and illegal logging, forest degradation from fire, forest degradation from woodfuel collection, and carbon stocks enhancement from on-reserve forest plantation establishment.**
- The **historic reference period is 2000-2015** and was selected based on the availability of land cover maps and the desire to include additional years to better represent more recent emissions associated with deforestation.
- Historical emissions from deforestation, forest degradation, and removals from carbon stock enhancement activities were **estimated using data and methods that can be primarily considered Tier 2 and 3 levels (T2 and T3).** The table below summarizes the data sources for activity data and emission/removal factors.

Activity	Activity Data	Emission/Removal Factor
Deforestation	Landsat satellite imagery (T3)	Field data collected by GFC (T3), Peer-reviewed published literature: Kongsager et al. (2013) (T2), IPCC defaults i.e. Tier 1 (T1)
Degradation by legal logging	Ghana Forestry Commission (GFC) records (T3)	Field data collected by GFC (T3)
Degradation by illegal logging	Peer-reviewed published literature: Hansen et al. (2012) for Ghana (T2/T3). However, for single point in	Field data collected by GFC (T3), but for legal practices. Illegal logging specific measurement

	time thus represents a proxy (T1)	needed in the future.
Degradation by fire	MODIS Burned Area Product (T2/3)	Field data collected by GFC (T3) for stocks. T1 assumptions for emissions.
Degradation by fuelwood collection	Global spatial datasets (T2/3), international databases (T1/2/3)	Plot data, forest inventories, empirically-derived maps of biomass distribution (T2), IPCC defaults (T1)
Enhancements	GFC records (T3)	Peer-reviewed published literature (T2/3) and IPCC defaults (T1)

- **Pools and greenhouse gases (GHGs)** were selected separately for each activity based on the expected magnitude of the change in stock in a given pool as well as the resources required to collect accurate and precise data.

The average annual historical emissions from all activities 2000-2015 was estimated at 61.6 million tCO_2e yr^{-1} and the average annual removals were 610 thousand t CO_2e yr^{-1}. Over 66% of emissions were due to deforestation, while legal and illegal logging made up 28% combined. Fuelwood and forest fire accounted for a minimal percentage of total emissions, making up just 6% and 1% respectively.

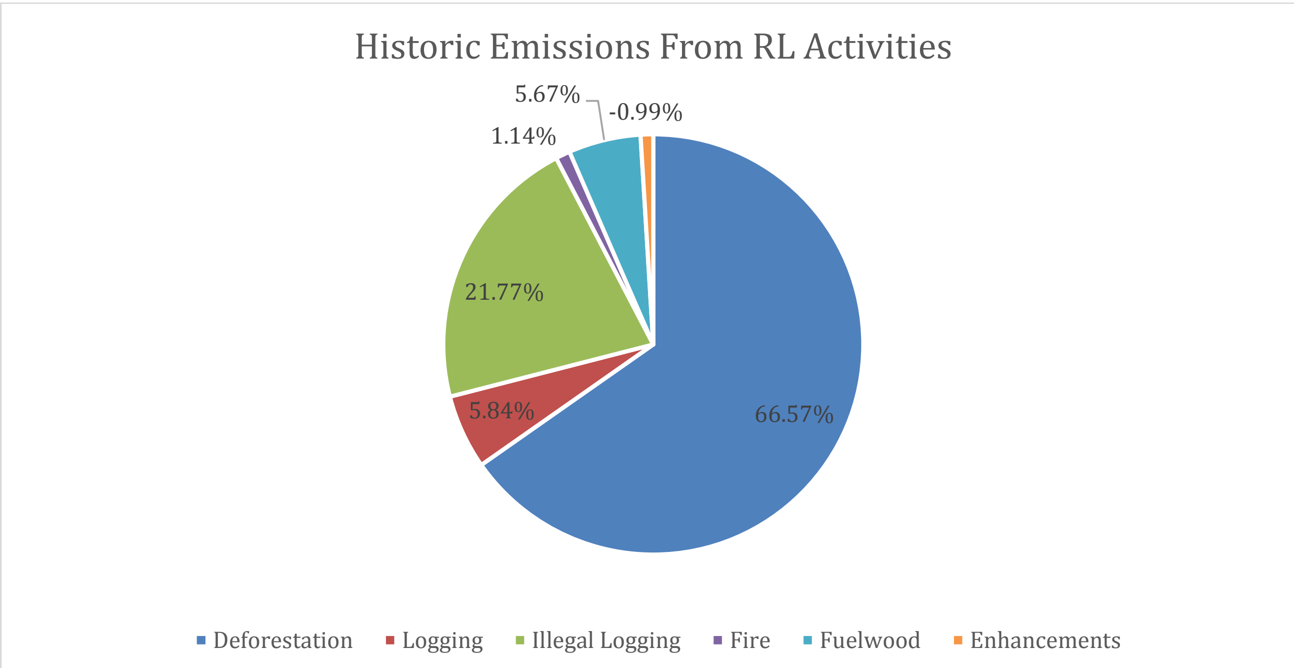

Figure 1 Contribution of Emissions Per REDD+ Activity

Based on the analysis of historical emissions, Ghana has developed its **National Reference Level utilising a continuation of historical trend. This projection** most accurately captures the historical emissions trends observed nationally. The trend was calculated by examining activities separately: a clear upward trend in emissions exists for deforestation; a downward trend in emissions from legal logging; and no trend was seen for all other activities so the average annual emissions rate was applied. Historic emissions and the proposed trend are shown below.

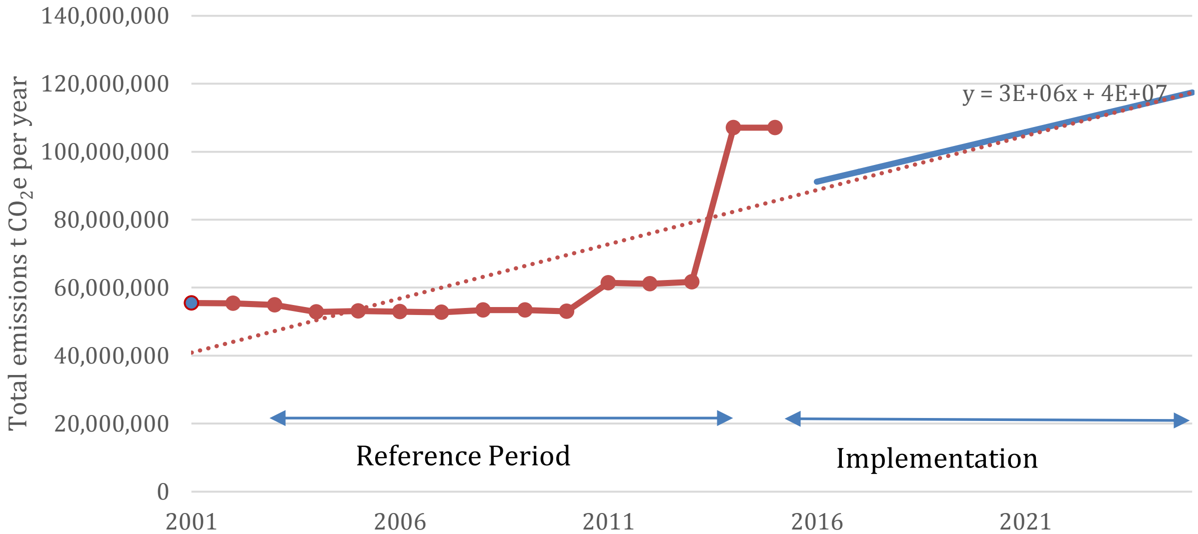

Figure 2 National Historic and Projected Emissions

The total uncertainty for the national FRL is 12.1%. In accordance with decision 12/CP.17, Ghana will undertake stepwise improvement of its national FRL as better datasets and more advanced methodologies become available. During the period of measurement and reporting against the FRL. Ghana will undertake further studies to update emission factors associated with the conversion of forests to tree crops. In addition, further work is also envisaged for the determination of nationally specific removal factors for non-teak forest plantations to replace the IPCC default values utilised in the development of the national FRL. For illegal logging, Ghana will explore alternative approaches for collecting activity data or systemically replicate the methodology applied by Hansen et al (2012) to ensure that activity data are estimated every two years. During the MRV phase, the WISDOM model for estimating emissions from woodfuel extraction will also be customised to meet Ghana's specific national circumstances and needs.

BACKGROUND

In accordance with decision 12/CP.17 paragraph 131, Ghana has deemed it appropriate to submit its proposed forest reference level (FRL) for consideration by the United National Framework Convention on Climate Change (UNFCCC). There are two main components of the FRL: (a) establishment of Ghana's historical emissions profile from the forestry sector and (b) the development of the proposed FRL. This report presents an overview of the data and methodologies used to estimate the historical emissions profile as well as details of how these baseline emissions were applied for the development of the FRL. The information presented is intended to be transparent, complete, consistent with UNFCCC guidance, accurate and guided by the most recent IPCC guidance and guidelines. We request the Secretariat to make this information available on the UNFCCC REDD web platform and hereby request a technical assessment of Ghana's initial proposal.

1.1 REDD+ in Ghana

Ghana's total forest cover is 5,768,678 ha and this area is divided into three main ecological zones; the High Forest zone (HFZ), Transitional Zone (TZ) and the Savannah Zone (SZ). These zones have been delineated based on climatic factors, notably rainfall and temperature. The main ecological zones are subdivided into nine forest strata.

Ghana's high forest zone (HFZ) in the southwest HFZ falls within the biodiversity hotspot of the Guinean forests of West Africa, one of the 36 most important biodiversity areas in the world.[2] The Transitional Zone exists in the mid-part of the country. It portrays characteristics of both the High Forest and Savannah Zones. The Savannah Zone mainly exists in the northern part of the country, but stretches further south into the east coast. These three main ecological zones are subdivided into strata as defined in section 3.1.

[2] Ghana Forestry Commission. 2015. Ghana National REDD+ Strategy. Available at: https://www.forestcarbonpartnership.org/sites/fcp/files/2016/Sep/Ghana%27s%20National%20REDD%2B%20Strategy%20Dec%202015.pdf

With a current rate of deforestation and forest degradation (3% annual loss of forest cover in Ghana), Ghana's forest resources face pressures from mining, agricultural encroachment, legal and illegal logging, woodfuel harvesting, wildfires and infrastructure development. Ghana's economic growth and achievements have come at a significant cost to its forests. Having lost over 60% of its forest cover from 1950 to the turn of the last century (2.7 million hectares)[3], and considering the current deforestation rate of approximately 3% per year (320,803 ha/year) since 2000 and a marked increase between 2013 and 2015 of 794,214 ha/year, the future of Ghana's forests is an issue of major concern.

Forest degradation and deforestation pose a significant threat to Ghana for two main reasons. Forests provide many ecosystem services and functions that support the country's predominantly agrarian economy. Therefore, the continual loss of Ghana's forests poses severe challenges to Ghana's economy as well as the capacity of forest ecosystems to sustainably supply critical goods and services for the country. In addition, deforestation is a major global contributor to climate change.. Ghana therefore runs the risk of remaining in its present status of a net emitter of CO_2 if it is unable to halt deforestation and forest degradation. Given that climate change poses myriad threats to Ghana as a result of projected increases in temperature and changes in rainfall patterns, the effort to mitigate and adapt to climate change is of paramount importance to all Ghanaians.

Ghana began its engagement in REDD+ in 2008 with the development of its Readiness Project Idea Note (R-PIN), and in 2010 received approval of its R-PP. Since 2010, Ghana has been focusing on REDD+ Readiness, building the needed capacity, understanding, architecture and systems to support the implementation and monitoring of REDD+ projects and programmes. In 2016, Ghana submitted its draft Emission Reduction Program Document (ER-PD) to the Forest Carbon Partnership Facility (FCPF) for its sub-national Ghana Cocoa Forest REDD+ Programme (GCFRP), which is concentrated in the HFZ (see figure 1).

[3] FAO, 2010. Global Forest Resources Assessment. Main report. Available at http://www.fao.org/docrep/013/i1757e/i1757e.pdf

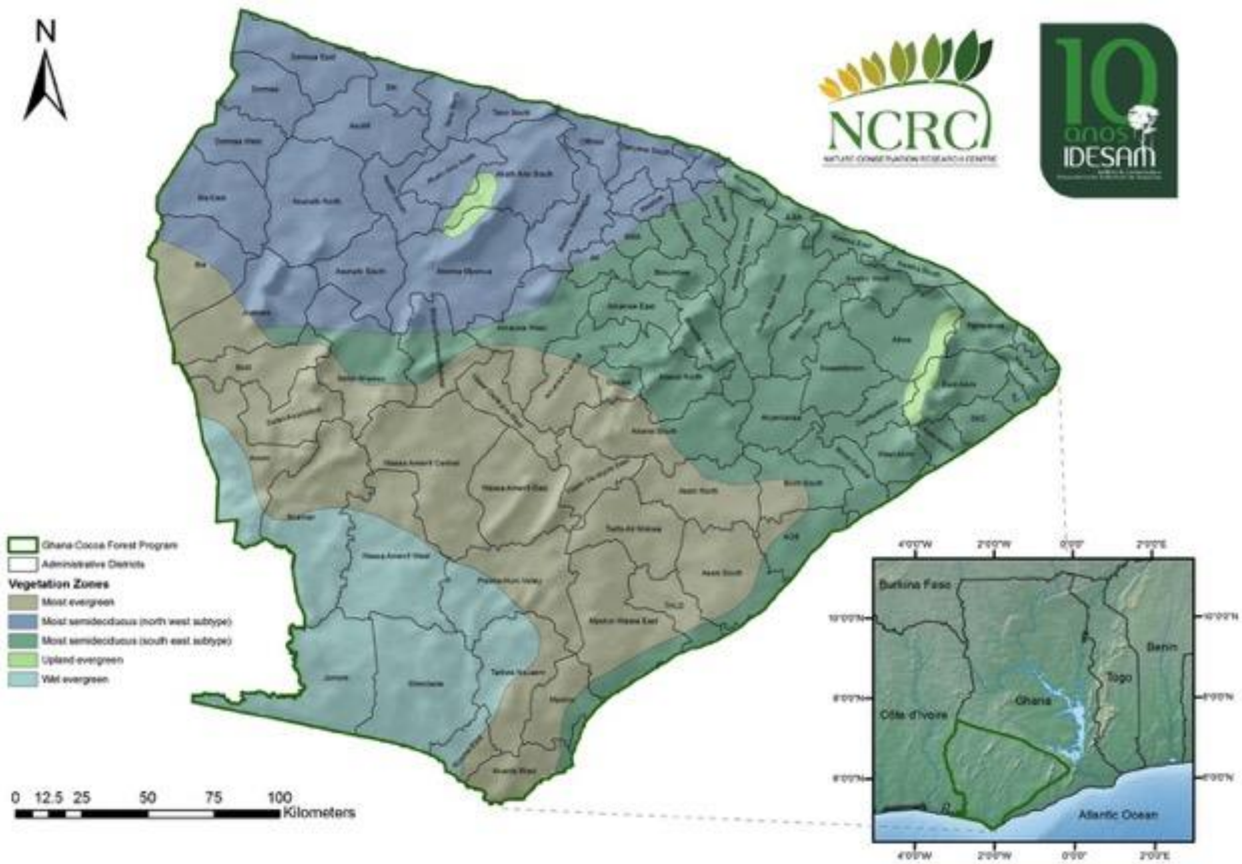

Figure 1: Ghana's forest ecosystem types in the FCPF GCFRP area in Ghana's high forest zone, and administrative regions.[4]

[4] Ghana Forestry Commission. October 2016. ER-PD – Ghana Cocoa Forest REDD+ Programme (GCFRP) Draft Submission. Available at: https://www.forestcarbonpartnership.org/sites/fcp/files/2016/Nov/Ghana%20advanced%20draft%20ER-PD.pdf

1.2 Application of UNFCCC Modalities to Ghana's FRL

Within the context of the United Nations Framework Convention on Climate Change (UNFCCC or Convention), REDD+ REL/RLs serve two purposes.[5] First, FRLs establish a business-as-usual (BAU) baseline against which actual emissions are compared, whereby emission reductions are estimated as the difference between FRLs and actual emissions. In this sense, FRLs depict what the emissions scenario would be in the absence of REDD+ implementation, and thus provides the basis for measuring its success. Second, FRLs are needed to determine the eligibility of UNFCCC Parties for international, results-based support for REDD+, and to calculate that support on the basis of measured, reported, and verified emission reductions.

The creation of forest FRLs as benchmarks for assessing performance are guided by modalities contained in UNFCCC Conference of Parties (COP) decisions, most notably decision 12/CP.17 and its Annex. These modalities state that when establishing FRLs, Parties should do so transparently taking into account historic data and adjusting for national circumstances in accordance with relevant decisions of the COP[6]. A step-wise approach is allowed that enables Parties to improve the FRL by incorporating better data, improved methodologies and, where appropriate, additional pools. FRLs are expressed in units of tons of CO_2 equivalent (CO_2e) per year and must maintain consistency with a country's greenhouse gas inventory (according to 12/CP.17, Paragraph 8). In response to the guidelines for submissions of information on FRLs provided in decision 12/CP.17, a summary of Ghana's decisions on these modalities is given in Table 1.

Table 1. UNFCCC modalities relevant for Ghana's national FRL.

Reference to Guidelines	Description	Ghana's Proposal
Decision 12/CP.17 Paragraph 1	Allows for a step-wise approach	Ghana has developed a sub-national FRL for the GCFRP and is using the same methodologies to extrapolate to the national level. Ghana plans to develop a nested-REDD+ program in the future.

[5] Meridian Institute. 2011. "Modalities for REDD+ Reference Levels: Technical and Procedural Issues." Prepared for the Government of Norway, by Arild Angelsen, Doug Boucher, Sandra Brown, Valérie Merckx, Charlotte Streck, and Daniel Zarin. Available at: http://www.REDD-OAR.org.
[6] Decision 4/CP.15, paragraph 7.

Reference to Guidelines	Description	Ghana's Proposal
Decision 12/CP.17 Annex, paragraph (c)	Pools and gases included	Pools: - Aboveground biomass is the most significant pool for forests in Ghana - Belowground biomass is significant - Litter included for completeness - Deadwood included for completeness - Herbaceous included for completeness - Soil is a significant pool Gases - CO_2 always accounted for emissions and removals - CH_4 and N_2O accounted for fires that cause deforestation and degradation. Converted into CO_2e
Decision 12/CP.17 Annex, paragraph (c)	Activities included	- Deforestation - Forest degradation from woodfuel collection, forest fire, legal timber logging, illegal timber logging - Carbon stock enhancement for removals from forest plantations that have been planted "on-reserve" lands[7].
Decision 12/CP.17 Annex, paragraph (d)	Definition of forest used is same as that used in national GHG inventory	- 15% canopy cover, - minimum height of 5 meters, and - minimum area of 1 hectare[8]
Decision 12/CP.17 Annex	The information should be guided by the	GHG estimates were developed integrating 2006 IPCC Guidelines.[9]

[7] All wooded vegetation demarcated and gazetted as forest reserves and national parks. They are constituted by statutory regulation and managed by the Forestry Commission of Ghana, for the provision of environmental and ecosystem services, production of timber for commercial purposes and protection and management of wildlife resources.

[8] Note: Tree crops, including cocoa, citrus, oil palm (in smallholder or estate plantations), and rubber are not considered to be forest trees. Timber tree plantations are considered forest under the national forest definition

[9] IPCC 2006 Guidelines for National GHG Inventories, Volume 4 AFOLU (IPCC 2006 AFOLU)

Reference to Guidelines	Description	Ghana's Proposal
	most recent IPCC guidance and guidelines.	
Decision 12/CP. 17 II. Paragraph 9	To submit information and rationale on the development of forest FRLs/FRELs, including details of national circumstances and on how the national circumstances were considered	Forest degradation and deforestation pose a significant threat to Ghana for two main reasons. Forests provide many ecosystem services and functions that support the country's predominantly agrarian economy. In addition, deforestation is a major global contributor to climate change through CO_2 emissions. Ghana therefore runs the risk of remaining in its present status of a net emitter of CO_2 if it is unable to halt deforestation and forest degradation

RATIONAL AND JUSTIFICATION OF GHANA'S DECISIONS FOR THE FRL

2.1 Scope of Activities

Ghana will include emissions from deforestation and forest degradation (legal and illegal logging, fuel wood and fire) as well as removals from carbon stock enhancement from tree plantations for land that is considered "on-reserve".[10]

Emission from deforestation are substantial in Ghana accounting for 41 $MtCO_2e$ since 2000 or 66% of emissions from the forestry sector (Figure 2).

[10] "on-reserve" refers to all wooded vegetation demarcated and gazetted as forest reserves and national parks. They are constituted bystatutory regulation and managed by the Forestry Commission of Ghana, for the provision of environmental and ecosystem services, production of timber for commercial purposes and protection and management of wildlife resources.

Emissions from fire are non-negligible (0.7 $MtCO_2e$ yr^{-1} at 1% of total emissions), especially in the northern savanna vegetation zone, which represents 62% of emissions from forest degradation from fire. Similarly, emissions related to fuel-wood collection (3.5 $MtCO_2e$ yr^{-1}, about 6% of total emissions are most substantial in the savanna vegetation zone.

Ghana has a developed logging sector that accounts for 3.6Mt CO_2e emissions annually on average (6% of total emissions). Although more precise estimates are not available, studies indicate that emissions from legal logging are less than a third of those of illegal logging activities that are estimated at about 13.4 M tCO_2e emissions per year which relates to 21% of total emissions (see annex A for more detail).

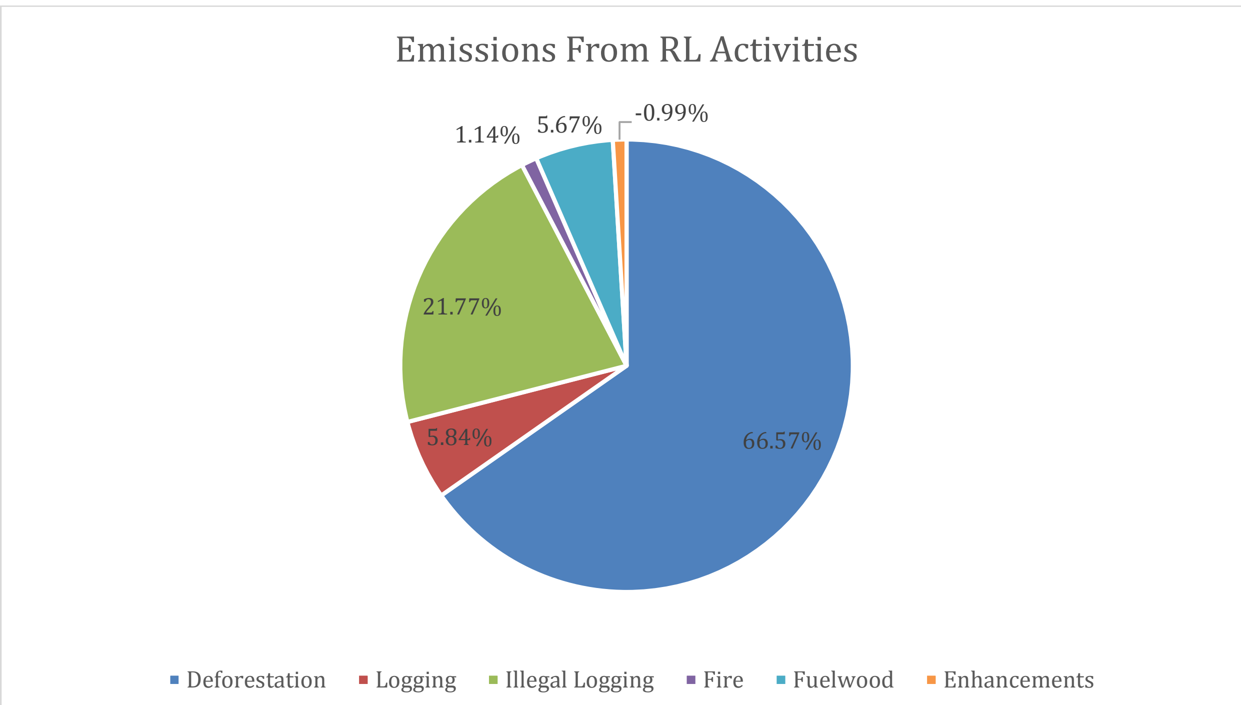

Figure 2. Relative emissions from REDD+ activities in Ghana.

2.2 Forest Definition

Following Ghana's National REDD+ Strategy[11], the definition used for Ghana's forest definition is a minimum of **15% canopy cover, minimum height of 5 meters, and minimum area of 1 hectare**,

[11] GoG, 2015. National REDD+ Strategy.

based on thresholds set by the IPCC for these structural parameters and the Marrakesh Accord. This definition is in line with the definition used in the most recent National Greenhouse Gas inventory.[12]

Tree crops, including cocoa, citrus, oil palm (in smallholder or estate plantations), and rubber are not considered to be forest trees. Timber tree plantations are considered forest under the national forest definition.

Agreement on this definition was reached following an intense consultative process in which three options were debated and discussed amongst a broad group of stakeholders. Consensus was reached on the definition stated above based on the strength of arguments adduced, however, it is important to note that not all participants in the process agreed with the outcome as they felt that the canopy cover and height parameters would exclude much of northern Ghana from participating in REDD+. It is noted that the UNFCCC will accept only a single forest definition for each country, and there is no option to provide different forest definitions for different ecological zones.

2.3 Scale

Ghana has developed a subnational FRL for the HFZ under the GCFRP, which has been submitted to the FCPF. For this submission to the UNFCCC, Ghana has decided to submit a national FRL which includes the GCFRP, so as to include estimated emissions across the country. The methods used for emission estimates are the same for both the subnational and national FRL and so any emission reductions credits purchased under the GCFRP can be readily subtracted from an eventual national program.

2.4 Pools and Gases

Pools for Ghana were selected separately for each activity included in the FRL (Table 2). The selection of pools was based on the expected magnitude of the change in stock in a given pool as a result of deforestation as well as the resources required to collect accurate and precise data.

For degradation caused by legal or illegal logging and fuel-wood, the soil carbon pool was not included because it has been shown that selective logging has no impact on soil carbon over a large

[12] Republic of Ghana, National Greenhouse Gas Inventory Report, July 2015. Table 72.

concession because of the small area impacted.[13] Litter was also not included in degradation because like the soil pool the impact is very small due to the small area impacted by logging.

For fire, all pools where included except for soil, as emission from soil are not significant under fire.

For carbon stock enhancement only above ground and below ground biomass are included as the other pools are not a significant source of additional removals.

Table 2. Carbon pools selected to include in the FRL according the activity.

Activity	AG Biomass	BG Biomass	Dead Wood	Litter	Soil Carbon
Deforestation	X	X	X	X	X
Degradation from illegal and legal logging	X	X	X		
Degradation from fire	X	X	X	X	
Degradation from fuel-wood	X	X			
Carbon stock enhancement	X	X			

The selection of greenhouse gases for Ghana includes CO_2 only. The exception is the non-CO_2 gases (nitrous oxide, N_2O, and methane, CH_4) that are included in the estimates of emissions from fire based on the IPCC 2006 AFOLU method and factors and converted to CO_2e.

2.5 Historic Time Period

The reference period for the construction of the FRL is from 2000-2015, and historical emissions will be estimated based on locally developed data and land cover maps. This period was initially selected to fall in line with the Carbon Fund Methodological framework and because existing land cover maps existed for 2000 and 2010. Additional activity data were created for 2013 and 2015 to provide the most accurate representation of Ghana's emission profile.

[13] Johnson, D. W. and P. S. Curtis. 2001. Effects of forest management on soil C and N storage: meta analysis. Forest Ecology and Management 140:227-238

2.6 Adjust for National Circumstances

According to Decision 12/CP.17 II. Paragraph 9, countries can submit information and rationale on the development of FRLs, including details of national circumstances and if adjusted include details on how the national circumstances were considered. However, Ghana does not wish to adjust its FRL to national circumstances as it feels that emission reported during the reference period are representative of current emissions.

HISTORICAL EMISSIONS METHODS

The development of the FRL and MRV is divided into steps based on the three key activity types (Figure 3). In addition, degradation is broken down further into four separate activities: degradation from legal timber harvest, degradation from illegal timber harvest, degradation from wood fuel collection, and degradation from fire. The section below provides details on the inputs used to develop historical emissions to support the establishment of the FRL, and the estimation of current emissions to support the establishment of an MRV system.

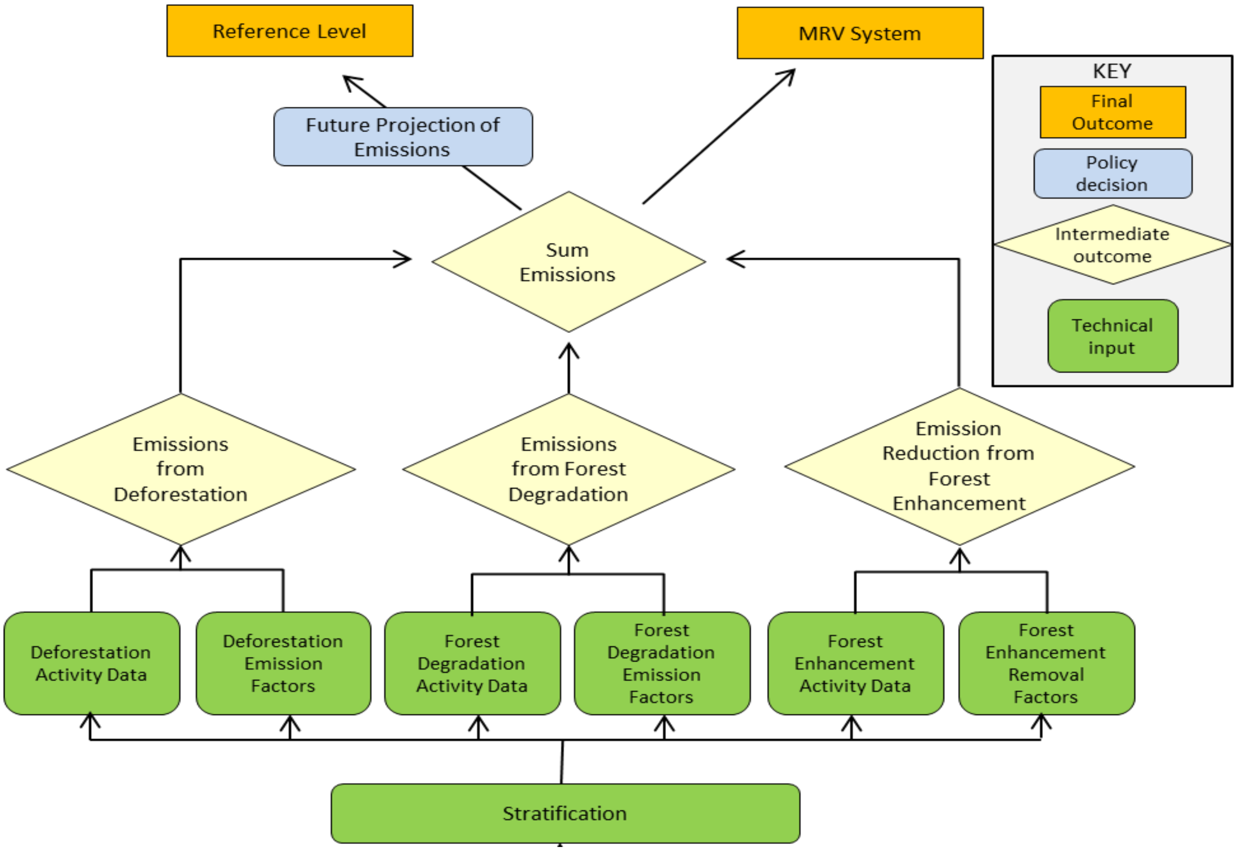

Figure 3: Framework for the National Forest Monitoring System to provide key input into the historical emissions for Reference Level Development and the Measuring, Reporting and Verification System.[14]

3.1 Stratification

The forests in Ghana are very diverse in terms of species composition and ecological landscape, which is influenced by soil structure and rainfall regime. Consequently, forest management in Ghana is structured to address the diversity of the forest resources within and across the ecological landscape.[15]

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[14] Based on Brown S., F. Casarim F., K.M. Goslee, A.M. Grais, T.H. Pearson, S. Petrova, E.Swails, S.M. Walker. 2013. Technical Guidance Series for the Development of a National or Subnational Forest Monitoring System for REDD+. Developed by Winrock International under the LEAF Program.

[15] Yakubu M. 2015. Standard Operating Procedure 004 – Stratification of Lands. Prepared in collaboration with and Indufor/Forest Consult/GISD for the Ghana Forestry Commission.

Guidance issued by the IPCC in the development of greenhouse gas inventories for the forestry sector requires stratification of forest lands. The Forest Preservation Programme (FPP) which conducted wall-to-wall mapping of forest resource in Ghana reported transformation of the forest structure and condition between 1990 and 2010. The information gathered under this program provided baseline information on the vegetation cover for Ghana to define the forest classes. The strata are divided into ecozones (see figure 4) and each ecozone is categorized into open and closed forest (see definitions below).

Dry Semi deciduous forest (inner and fire zone)

It has a wide range of annual rainfall (1000 -1500mm), it is heavily degraded because of frequent wildfires. Large portion of the gazetted natural forests have been converted to plantations. The vertical structure is between 30-45-m. Most gazetted forest reserves are found within this zone.

Evergreen forest moist

This is forest that remains green throughout the year and does not shed its leaves. Tree upper canopy trees grows up to 43m high. This strata is very rich in species diversity and annual rainfall ranges from s 1500-1750mm. The soil PH is 3.8-4.3.

Evergreen forest wet

This is forest that remains green throughout the year and does not shed leaves. Upper canopy trees rarely exceed 40m high. This strata is very rich in species diversity and annual rain fall exceeds 1750mm. The soil PH is 3.8-4.3.

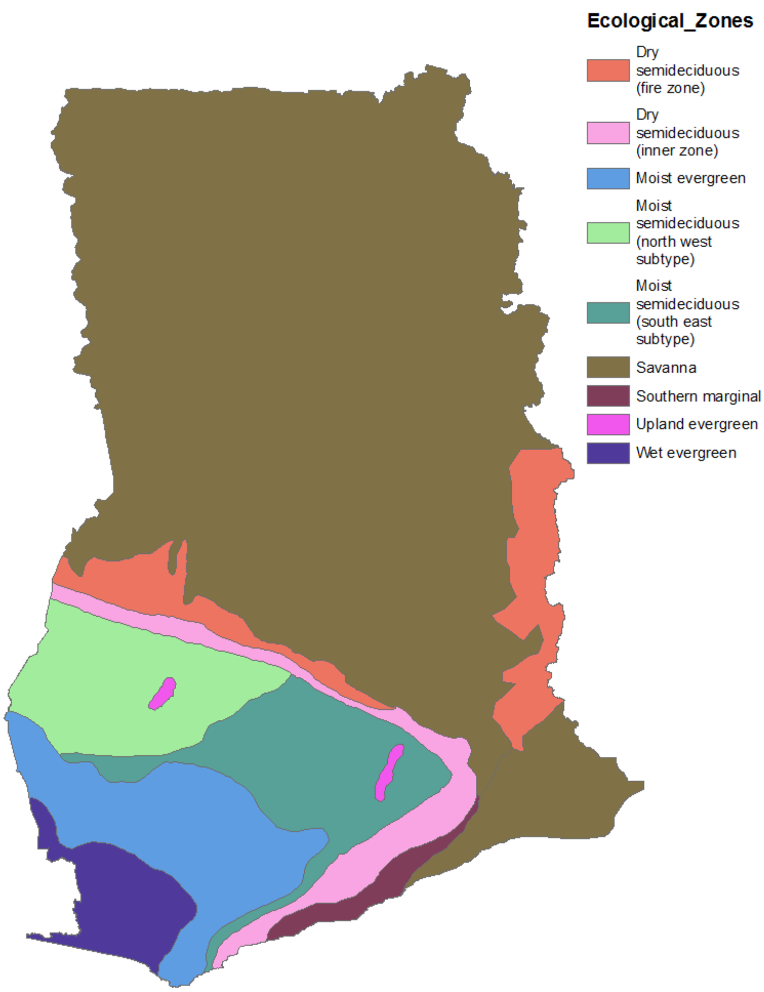

Figure 4: Ecological zones in Ghana.[16]

Moist semi deciduous south east forest

A mixture of evergreen and deciduous species. It is the most productive among the forest zones. Diversity is lower - about 100 trees/ha, but majority of commonest species in Ghana achieve their

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[16] Map prepared by the GIS and mapping unit at RMSC, 2014

greatest frequency in this zone. Tree height in the upper canopy is between 50-60 m. The soil PH is 5-4 and comparatively richer than the evergreen forest. Annual rain fall is 1250-1750mm.

Moist semi deciduous north west forest

Has similar attributes to the Moist semi-deciduous south east forest. Most of the gazetted forest reserves are found within this zone.

Savanah woodland

Woodland vegetation found in the northern and coastal savannah of Ghana. Northern savannah is mainly woodlands and grass mosaic. Trees can grow above 5 meters. However, along rivers and streams, the tree height can reach up to 20 meters and usually forms a closed canopy. The forest in this zone is fire prone, and fire is sometimes used as management for the range lands.

Southern Marginal

The Southern Marginal forest is shorter than 30m, has thick undergrowth and may include high densities of multiple species.

Upland Evergreen

This is forest that remains green throughout the year and does not shed leaves. Upper canopy trees exceed 43m high. Very rich in species diversity and annual rain fall exceeding 1250-1750mm. The soils are much more rich than the moist and wet evergreen, however species diversity is much lower.

Ghana's forest cover can also be categorized into open and close forests depending on the canopy cover thresholds:

Closed canopy forest

Under the Forest Preservation Programme Ghana's forest was classified according to the extent of canopy cover. The closed canopy forests are those with canopy cover exceeding 60%. It exhibits typical high forest characteristics with a 3-layer vertical structure namely; the upper, middle and ground layers. They are mainly found in the gazetted forest reserves and national parks of Ghana. This category of forest according to the Resource Management Support Centre (RMSC) categorization which is based on the amount of light that penetrates the forest floor and is referred to as condition score varying from 1 to-6 in order of good to bad condition, have condition score 1 and 2.

Open canopy forest

This is modified or disturbed natural forest which has 15 - 59 % canopy cover (FPP, 2010.) They may also have a three vertical layer structure: an upper layer which is made up of isolated mature trees; the middle layer is made up of saplings and shrubs; and a ground layer which is dominated by grass. In most instances, the middle and ground layers are merged and constitute the dominant layer in the open forest. Open canopy forests exists mainly outside the gazette forest reserves. Degraded forest reserve with condition score 4 and above also fall into this category.

3.2 Deforestation

3.2.1 Activity data

Activity data were obtained from the 2000, 2010, 2013 and 2015 land cover maps based on 30 m resolution Landsat imagery classified using NDVI.[17] The 2000 land cover map was used to establish the time-zero forest extent for Ghana that was then used to develop a forest "mask." Losses in forestland cover, i.e. deforestation, were only counted if pixels classed as forest in the 2000 forest mask changed to non-forest in a subsequent land cover map (see figure 5).

For the GCFRP Accounting Area a separate study of plantations of agricultural tree crops was conducted using high-resolution imagery (methods in Annex B), to allow removal of agricultural tree areas from deforestation totals and addition to the deforestation totals of areas where agricultural tree plantations replaced natural forest. This step was undertaken to ensure that plantations of agricultural tree crops were not accounted for in the FRL.

Total deforestation was estimated as the sum of all the pixels in the 2000 forest mask that changed to non-forest between 2000, 2010, 2013 and 2015. The annual historical average was derived by dividing total deforested area (2000-2015) by the number of years (15):

Annual average activity data = total deforestation / number of years

Areas of deforestation caused by fire were identified using the MODIS burned area product, as discussed below in the degradation by fire section. Areas identified as burned and also as deforested

[17] Land cover maps developed by the Forest Preservation Programme (FPP) project for 2000 and 2010[17]; remote sensing analysis conducted by RMSC for 2013 and 2015, Applied Geo-Solutions (AGS) remote sensing analysis on differentiating natural forest from tree crops (see Annex C).

were assumed to be deforested by fire. Since the land use maps used for deforestation accounting were not annual but the burn scar maps used for forest fire accounting were annual, it was assumed that any fire registered in the deforestation period was associated with the deforestation event and any additional fires were in an agricultural (outside REDD) context. Thus no degradation is recorded by fire if a fire occurs in the same period as deforestation. Deforestation fires were only tracked for one year for each of the three deforestation periods. The year at the beginning of each deforestation period was used; meaning deforestation fires were only accounted for in 2001, 2010 and 2013.

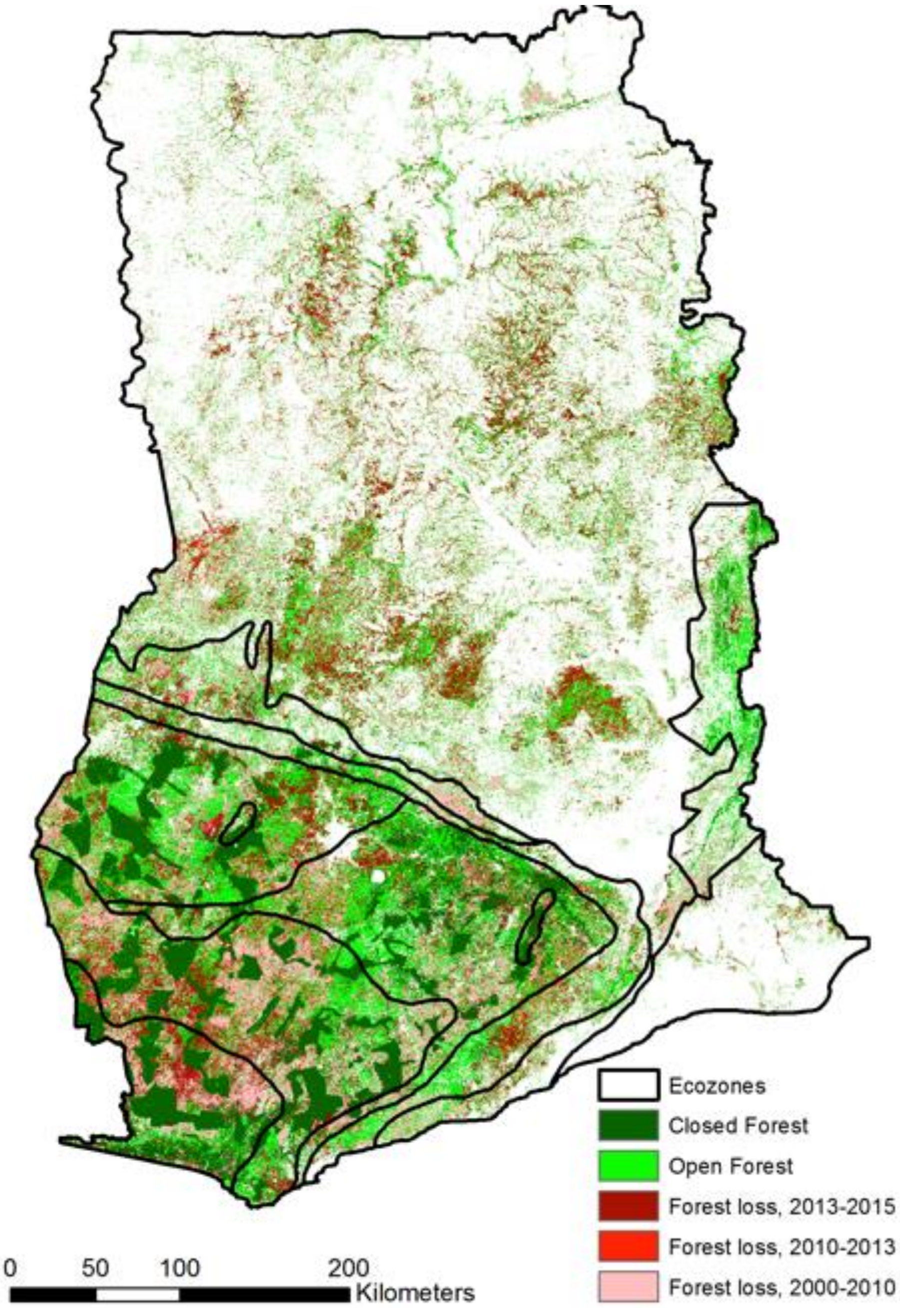

Figure 5. Deforestation in Ghana between 2000 and 2015.

The activity data for deforestation is presented in table 3 below.

Table 3. Activity data for deforestation in Ghana between 2000 and 2015.

2001-2010	Crop-land	Oil Palm	Cit-rus	Rubber	Cocoa	Grass-land	Wet-lands	Settle-ment	Bareland / other	Water	Total
Open Forest	852,565	14,568	2,428	7,284	99,562	801,388	1,015	15,517	11,265	7,353	1,812,946
Closed Forest	153,624	19,244	3,207	9,622	122,065	65,595	187	2,144	4,029	3,456	383,173
Total	1,006,189	33,812	5,635	16,906	221,627	866,983	1,202	17,661	15,294	10,809	2,196,118
2010-2013											
Open Forest	348,161	5,325	887	2,662	38,185	389,530	549	2,968	2,458	1,265	791,992
Closed Forest	56,282	7,938	1,323	3,969	51,040	28,722	45	318	548	452	150,636
Total	404,443	13,263	2,210	6,631	89,226	418,252	594	3,286	3,006	1,717	942,628
2013-2015											
Open Forest	487,743	8,185	1,364	4,092	61,874	751,970	568	58,433	5	2,677	1,376,912
Closed Forest	76,686	9,231	1,539	4,616	71,446	37,655	396	9,031	12	907	211,517
Total	564,429	17,416	2,903	8,708	133,320	789,625	964	67,465	17	3,584	1,588,429

3.2.2 Emission Factors

Deforestation emission factors were developed according to the stock-difference[18] approach provided by the IPCC Guidelines (2006), and represents the difference between the pre-deforestation carbon stocks and post-deforestation carbon stocks for each stratum (see Eq. 1).

$$EF_{def(t,x,y)} = (C_{bio.pre(x)} - C_{bio.post(t,y)} + \Delta SOC_{(t)}) * 44/12 + L_{fire} \qquad \text{Eq. 1}$$

Where:

$EF_{def(t,x,y)}$ = Emission factor for year t for deforestation for stratum *x* and driver *y*, $tCO_2e\ ha^{-1}$
$C_{bio.pre(x)}$ = Carbon stock in biomass in stratum *x,* prior to deforestation, $t\ C\ ha^{-1}$
$C_{bio.post(t,y)}$ = Carbon stock in biomass in year t post-deforestation, for driver *y*, $t\ C\ ha^{-1}$
$\Delta SOC_{(t)}$ = Change in soil carbon stocks in year t following deforestation, $t\ C\ ha^{-1}$
44/12 = Conversion factor from carbon to CO_2
L_{fire} = Emissions from burning, including non-CO_2 gases such as methane and nitrous oxide, expressed in CO_2 equivalents, $tCO_2e\ ha^{-1}$

The total biomass carbon stock for each stratum is the sum of all carbon stocks from measured pools (Equation 2), excluding soil carbon pool, which is reported separately.

$$C_{bio.pre(x)} = (C_{agb(x)}+C_{bgb(x)}+C_{dw(x)}+C_{lit(x)}+C_{veg(x)}) \qquad \text{Eq.2}$$

Where:

$C_{bio.pre(x)}$ = Carbon stock in biomass in stratum *x,* prior to deforestation, $t\ C\ ha^{-1}$
$C_{agb(x)}$ = Carbon stock in aboveground live tree biomass in stratum *x*, $t\ C\ ha^{-1}$
$C_{bgb(x)}$ = Carbon stock in belowground live tree biomass in stratum *x*, $t\ C\ ha^{-1}$
$C_{dw(x)}$ = Carbon stock in deadwood pools in stratum *x*, $t\ C\ ha^{-1}$ (includes both standing and lying deadwood)
$C_{lit(x)}$ = Carbon stock in litter in stratum *x*, $t\ C\ ha^{-1}$
$C_{veg(x)}$ = Carbon stock in non-tree vegetation in stratum *x*, $t\ C\ ha^{-1}$ (includes shrubs, sapling, and herbaceous understory)

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[18] UNFCCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use (AFOLU), Generic Methodologies Applicable to Multiple Land-Use Categories, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf

Strata were identified through the Forest Preservation Programme (FPP) Mapping of Forest Cover and Carbon Stock in Ghana project and represent all relevant IPCC land cover classes. In some strata, where open forests were converted to plantations of agricultural tree crops, the change in carbon stocks resulted in net removals. As this is assumed to introduce perverse incentives into the REDD+ programme, an emission factor of zero was applied. The EF for deforestation are given in Table 4 below. For full methodological approach see Annex A.

Table 4. Emission factors for all strata

Forest carbon Stratum/ Forest type	Land Cover	EF (t CO_2e/ha)
Wet evergreen		
Closed forest	Cropland	584.1
	Oil Palm	314.3
	Citrus	243.9
	Rubber	116.3
	Cocoa	243.9
	Grassland	520.2
	Wetlands	521.3
	settlement	589.5
	Bareland/other	674.1
Open Forest	Cropland	202.6
	Oil Palm	0.0
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	138.7
	Wetlands	139.9
	settlement	208.1
	Bareland/other	292.6
Moist Evergreen		
Closed forest	Cropland	651.8
	Oil Palm	436.4
	Citrus	366.0

	Rubber	238.4
	Cocoa	366.0
	Grassland	649.4
	Wetlands	639.7
	settlement	704.5
	Bareland/other	784.8
Open Forest	Cropland	119.8
	Oil Palm	5.9
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	180.9
	Wetlands	175.8
	settlement	210.2
	Bareland/other	252.8
Moist Semidecidious SE		
Closed forest	Cropland	478.8
	Oil Palm	413.0
	Citrus	342.6
	Rubber	215.0
	Cocoa	342.6
	Grassland	571.3
	Wetlands	578.2
	settlement	608.4
	Bareland/other	645.8
Open Forest	Cropland	60.9
	Oil Palm	15.1
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	166.0
	Wetlands	173.7
	settlement	173.7
	Bareland/other	227.9
Moist Semidecidious NW		
Closed forest	Cropland	224.2
	Oil Palm	43.6
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	219.6

	Wetlands	224.9
	settlement	216.9
	Bareland/other	325.2
Open Forest	Cropland	100.4
	Oil Palm	0.0
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	105.8
	Wetlands	111.8
	settlement	143.8
	Bareland/other	201.4
Upland Evergreen		
Closed forest	Cropland	388.1
	Oil Palm	182.7
	Citrus	112.3
	Rubber	0.0
	Cocoa	112.3
	Grassland	373.1
	Wetlands	376.1
	settlement	431.9
	Bareland/other	501.1
Open Forest	Cropland	120.3
	Oil Palm	0.0
	Citrus	0.0
	Rubber	0.0
	Cocoa	135.6
	Grassland	149.6
	Wetlands	155.8
	settlement	155.8
	Bareland/other	233.3
Dry Semideciduous inner zone		
Closed forest	Cropland	279.3
	Oil Palm	0.0
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	157.5
	Wetlands	157.1
	settlement	235.3
	Bareland/other	332.3

Open Forest	Cropland	173.7
	Oil Palm	0.0
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	103.8
	Wetlands	107.1
	settlement	107.1
	Bareland/other	226.7
Dry Semideciduous fire zone		
Closed forest	Cropland	109.7
	Oil Palm	0.0
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	60.8
	Wetlands	59.4
	settlement	102.4
	Bareland/other	155.7
Open Forest	Cropland	135.0
	Oil Palm	0.0
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	86.1
	Wetlands	84.6
	settlement	84.6
	Bareland/other	209.6
Savannah		
Closed forest	Cropland	149.9
	Oil Palm	0.0
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	19.3
	Wetlands	68.9
	settlement	124.7
	Bareland/other	193.9
	Water	68.9

Open Forest	Cropland	156.9
	Oil Palm	0.0
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	26.3
	Wetlands	75.9
	settlement	75.9
	Bareland/other	200.9
	Water	75.9
Southern Marginal		
Closed forest	Cropland	177.1
	Oil Palm	0.0
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	96.7
	Wetlands	115.5
	settlement	157.3
	Bareland/other	209.1
Open Forest	Cropland	128.1
	Oil Palm	0.0
	Citrus	0.0
	Rubber	0.0
	Cocoa	0.0
	Grassland	44.4
	Wetlands	62.9
	settlement	62.9
	Bareland/other	160.1

3.3 Degradation from legal timber harvest

Calculations and final estimation of emissions follow the methods outlined by Pearson et al. (2014)[19]. This method combines data on harvest volume (activity data) with an emission factor that reflects three emission sources that occur as a result of logging:

1. emissions from the milling, processing, use and disposal of the felled timber-tree,
2. emissions from incidental damage caused by the timber-tree fall and cutting of the log in the forest, and
3. emissions from infrastructure associated with removing the timber of the forest (e.g. skid trails, logging decks and logging roads).

The total emission factor from selective logging is estimated as the sum of three factors:

$$TEF = ELE + LDF + LIF$$

Where:

TEF Total emission factor (t CO_2 m^{-3})

ELE Emissions from extracted log (t CO_2 m^{-3})

LDF Logging damage factor (t CO_2 m^{-3})

LIF Logging infrastructure factor (t CO_2 m^{-3})

A committed emissions approach is employed in the calculations to simplify the carbon accounting process. This means that all emissions are accounted in the year of the logging event.

The TEF is then multiplied by annual timber extracted, in cubic meters per yr. from 2000-2015. Further detail on the methodology and assumptions made can be found in Annex B.

The legal timber harvest measurement approach is a direct accounting method using locally generated activity data and emissions factors – as such it is not a proxy-based approach. The activity data is the recorded volumes of extracted timber, emission factors are derived from field measurement in Ghana and capture the change in carbon stocks as a result of the extracted volumes. For the sake of precision, the method does not look at the difference in forest carbon stocks with

[19] Pearson T.R.H., Brown, S. and Casarim, F. 2014. Carbon Emissions from Tropical Forest Degradation Cause by Logging. Environ. Res. Lett. 9 034017 (11pp). Winrock International. Available at: http://www.winrock.org/sites/default/files/publications/attachments/Pearson%20et%20al%202014%20Logging.pdf

and without logging, which would be challenging and imprecise to measure. Instead, the change associated directly with each extracted cubic meter is estimated. The method thus involves only measurement of trees that have been felled or accidentally killed. As the measurement takes account of the whole dead trees, dead wood stocks and arguably even litter are effectively captured. The method also tracks the biomass extracted from the forest in the timber logs and thus captures harvested wood products, however, the simplifying assumption of committed emissions is applied so the only storage in wood products is the stock estimated to still be in use 100 years after harvest.

3.3.1 Activity data

Ghana has timber extraction data for the entire historical period 2000-2015. These data present the total volumes of timber extracted annually by species and by administrative unit (region and locality) based on the Tree Information Forms (TIFs). These data are summed annually across administrative units to calculate total volumes.

3.3.2 Emission Factors

Emission factors were derived from the methods in Pearson et al. (2014) and field data collected by the Ghana Forestry Commission in May 2016. The method takes a committed emissions approach. For harvested wood products, a 30-year half-life is used following the IPCC (2006) [20] default value for solid wood (Table 12.2), any products still in use 100 years after harvest are considered permanently sequestered. Further details are provided in Annex A.

The calculated values are summarized in Table 5 below,

Table 5. Estimated EF value for timber for legal timber harvest and associated uncertainty.

Factor		Value (tCO_2/m^3)	Uncertainty
Emission from Extracted Log	**ELE**	0.79	0.02
Logging Damage Factor	**LDF**	2.46	0.17
Logging Infrastructure Factor	**LIF**	0.50	0.13
Total Emission Factor	**TEF**	3.75	0.21

[20] UNFCCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use (AFOLU), Generic Methodologies Applicable to Multiple Land-Use Categories, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf

3.4 Degradation from illegal timber harvest

The approach for illegal timber harvest should be considered as a proxy method, as it relies on numbers for activity estimation from a published study for one point in time. The emission factors are Tier 2 and follow the same assumptions as legal logging. The method involves only measurement of trees in Ghana that have been felled or accidentally killed. As the measurement takes account of the whole dead trees, dead wood stocks and arguably even litter are effectively captured. The method also tracks the biomass extracted from the forest in the timber logs and thus captures harvested wood products, however, the simplifying assumption of committed emissions is applied so the only storage in wood products is the stock estimated to still be in use 100 years after harvest.

3.4.1 Activity Data

Yearly activity data on the amount of timber harvested illegally in Ghana are not available at this time (but will become so as the MRV system is implemented). Instead, a number of studies have been conducted that provide estimates on the amount of illegal timber harvest. The study, 'Revisiting Illegal Logging and the Size of the Domestic Timber Market (Hansen et al. 2012) provides activity data on historical illegal timber harvest for Ghana's FRL.

Hansen et al (2012) estimated illegally logged timber at 4.1 million m^3 per year in 2009 nationally. These numbers will be improved in a step-wise manner as Ghana develops a measurement system for illegal timber.

3.4.2 Emission Factor

Illegal timber harvest does not differ in felling practices from legal timber harvest. Differences arise in the milling efficiency (chainsaw milling in the forest), and in extraction (milled timber carried out by hand rather than skidded out) (see Annex A for further detail on the methodology used and Table 6 for the emission factors).

Table 6. Estimated EF value for timber for legal timber harvest and associated uncertainty.

Factor		Value (tCO_2/m^3)	Uncertainty
Emission from Extracted Log	**ELE**	0.81	0.03

Logging Damage Factor	**LDF**	2.46	0.17
Total Emission Factor	**TEF**	3.27	0.17

3.5 Degradation from forest fire

The measurement approach for fire uses spatial data to capture area burned annually and IPCC factors to derive emission factors. The biomass values input incorporate live biomass (above and belowground) as well as down dead wood and litter as stocks impacted by degradation caused by forest fires. These stocks are derived from the FPP (as for deforestation).

Total emissions from forest fire were estimated using Equation 2.27 from IPCC (2006)[21]:

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

Where:

L_{fire}= amount of greenhouse gas emissions from fire, tonnes of each GHG

A = area burnt, ha

M_B= mass of fuel available for combustion dry tonnes biomass ha^{-1}

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 0.32 (less intense) to 0.50 (more intense), dimensionless

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

3.5.1 Activity Data

The MODIS burned area product was used to identify areas that experienced emissions due to forest fire between 2001-2015. Only forest areas that remain forested and where forest fires occur but cause no change in land use were counted as forest degradation. Any areas that burned and were identified as deforestation were removed from degradation forest fire accounting. The analysis of

[21] IPCC (2006) Guidelines for national greenhouse gas inventories. Volume 4: Agriculture, Forestry, and Other Land Use. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

agricultural tree plantations (methods discussed in Annex B) was used to adjust the burned area totals to account for fires that occurred on agricultural tree plantations rather than forestland in the high forest zone, yet were classified as forestland by the land cover maps. Many areas experienced fires in several of the reference period years (Figure 6). Outside of the GCFRP, areas that experienced fires and then subsequently experienced deforestation were common. In these areas, the fires that occurred in prior periods before the deforestation event were accounted for as forest fires that cause forest degradation.

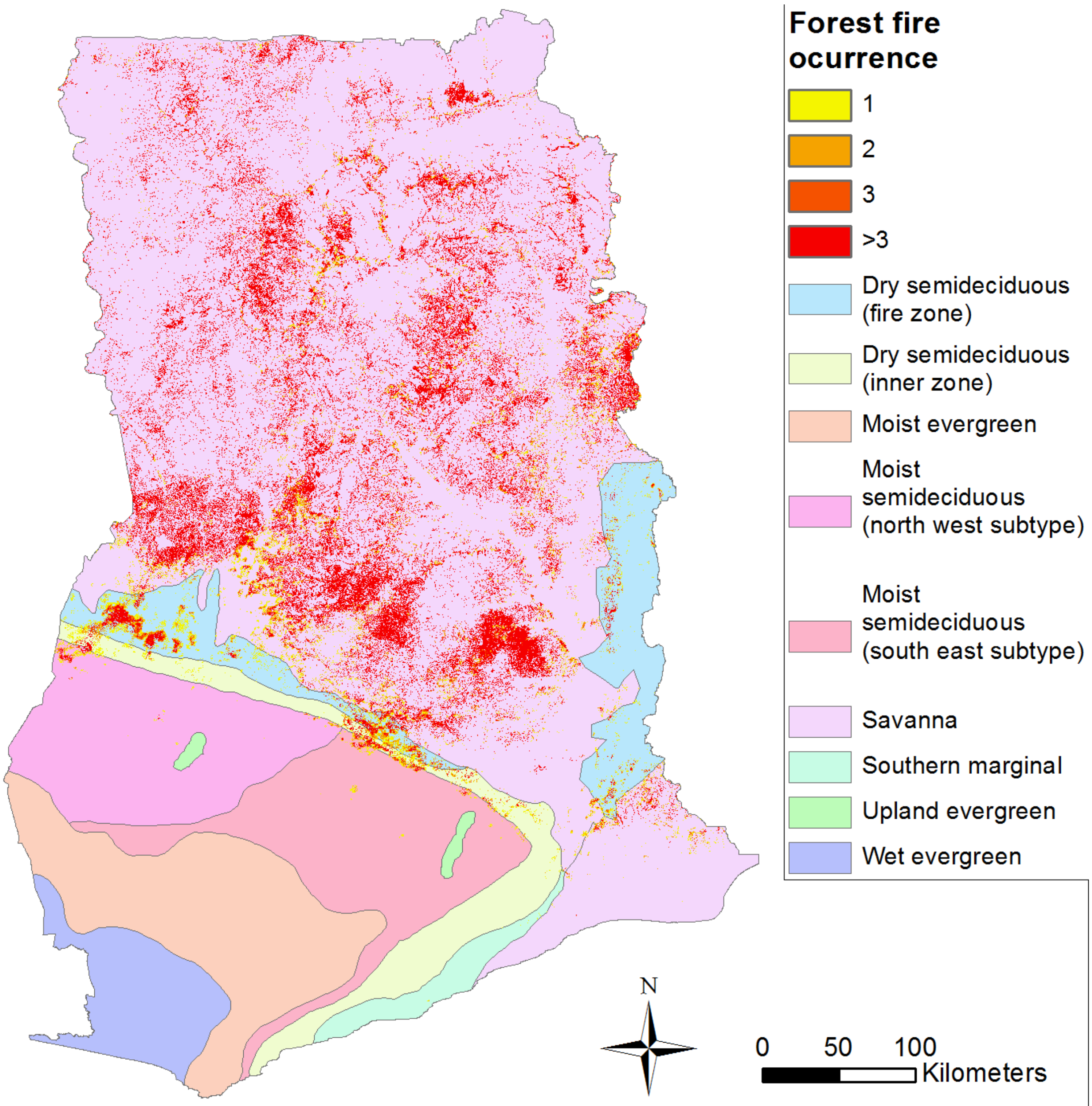

Figure 6: Forest fire occurrence in Ghana from 2001-2015

3.5.2 Emission Factor

Emission factors for fire are a combination of several factors: the biomass available for combustion (M_B), the combustion factor (C_f), and the emission factor (G_{ef}) for each key gas. M_B values were the same as used for deforestation, corresponding to the sum of the biomass stored in aboveground, belowground, deadwood, and litter pools in each of the ecozones. The combustion and emission factors were taken from IPCC (2006) Tables 2.6 and 2.5 respectively. One combustion factor, corresponding to primary tropical forests, was applied to all ecozones. Emission factors for tropical forests were applied for the three included gases, CO_2, CH_4, and N_2O.

Table 7. Combustion and emission factors applied for forest fire accounting.

Combustion Factor		
All gases	0.36	IPCC Table 2.6
Emission factor		
CO_2	1580	IPCC Table 2.5
CH_4	6.8	Tropical forests
N_2O	0.2	Tropical forests
Conversion factor to CO_2e		
CH_4	28	IPCC 2013
N_2O	265	IPCC 2013

3.6 Degradation from Woodfuel

The measurement approach is to model supply and demand of fuelwood in the program area. This analysis was conducted for a single point in time. It can be considered a proxy-based approach. The supply of fuelwood captures the losses that occur to both above and belowground tree biomass when trees are felled for timber. Other pools are considered insignificant with degradation through fuelwood extraction.

The Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM)[22,23] approach is used to estimate carbon emissions from woodfuel use. The WISDOM approach models demand and supply dynamics and produces an estimate of non-renewable biomass (in tonnes) that is extracted for woodfuel use. Emissions can then be estimated by converting the estimate of non-renewable biomass into carbon, and then into CO_2 emissions.

An expansion factor of 1.32 was applied to the WISDOM estimates of non-renewable biomass to conservatively estimate the total biomass that is emitted as a result of woodfuel harvesting that results in forest degradation. This factor was taken from the American Carbon Registry's *Energy efficiency measures in thermal applications of non-renewable biomass methodology*[24], based on the CDM-approved methodology AMS-II.G, Version 05.0. This factor of 1.32 was based on the assumption that for every unit of biomass extracted from the forest, an additional 10% is left in the field from uncollected aboveground biomass. A further 20% was conservatively estimated to remain from root biomass. These factors, multiplied together, produced a 1.32 expansion factor.

Estimates of CO_2 emissions from woodfuel use in Ghana are available for the year 2009 produced using the WISDOM approach[25] at the district level (a full list of district-level non-renewable biomass estimates and emissions are included in Section 4.2). These estimates serve as a Tier 2 estimate of woodfuel emissions, but are not accompanied by uncertainty estimates. Instead, to be highly conservative an uncertainty equal to 50% of the given values will be applied. The estimates are for the year 2009, and therefore do not offer multiple data points with which to develop a true historical average of woodfuel emissions. Nevertheless, annual emissions for 2009 was used to represent annual emissions for each year in the historical reference period. Future work will create annual data while increasing the precision of woodfuel use estimates.

3.7 Enhancement of carbon stocks

The measurement approach relies on national statistics on areas planted in forest reserves, and applies removal factors representing the growth of planted trees. Ghana-specific numbers are included for teak but IPCC defaults are applied for other species. Only accumulation in above and

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[22] http://www.wisdomprojects.net/global/ Developed by Bailis et al. (2015)
[23] Bailis et al. (2015). The carbon footprint of traditional woodfuels. Nature Climate Change 5, 266-272. http://www.nature.com/nclimate/journal/v5/n3/full/nclimate2491.html?WT.ec_id=NCLIMATE-201503
[24] http://americancarbonregistry.org/carbon-accounting/standards-methodologies/energy-efficiency-measures-in-thermal-applications-of-non-renewable-biomass/acr-ams-ii-g_v-5-0_final.pdf

belowground live tree biomass is included. All other pools are insignificant and given the increase in sequestration in the implementation case versus the FRL, any exclusion of pools is conservative.

The National Forest Plantation Development Programme (NFPDP) has engaged in a range of tree planting activities including a range of species (*Tectona grandis, Cedrela odorota, Gmelina spp., Terminalia superba, Triplochiton scleroxylon, Mansonia altissima, Khaya anthotheca, Terminalia ivorensis, Pycnanthus angolensis*). Teak is the dominant species planted in Ghana, hence activity data and removal factors for enhancement are categorized into two sub activities:

1. Establishment of teak species
2. Establishment of other broadleaf species

To track historical removals from enhancement activities in Ghana, we assume committed removals. This allows for a simplified accounting system that does not require tracking individual planted hectares over the course of their lifetime. Understanding that this approach invariably leads to an overestimation of historic removals as plantation activities are subject to failure due to management failures or natural causes, the committed removals are discounted by integrating estimates of plantation failure rates. These estimates of failure rates were derived from official records.

Furthermore, NFPDP activities involve planting commercial timber species that are subject to eventual harvest. Areas under timber management are replanted with commercial timber species at the completion of each harvest cycle. Therefore, the committed sequestration of a timber plantation is equal to the average carbon stocks of forest plantations over multiple harvest cycles.

3.7.1 Activity Data

While spatial data were not available on area planted, historical tabular data are organized into hectares planted per forest reserve. The NFPDP collects data for on-reserve tree establishment across Ghana, and include a number of programmes that took place along different timeframes between 2002-2015: Government Plantation Development Programme (GPDP), Modified Taungya System (MTS), Community Forestry Management Project (CFMP), Model plantations, and other on-reserve planting programmes (detailed in Annex A).

To account for plantation failure, the recorded annual area planted nationally was discounted based on official statistics from the NFPDP. These official statistics reflect the two distinct periods of activities that the NFPDP undertook, whereby the 2001-2009 period reflected plantation activities in forest reserves largely led by the public sector. Starting in 2010, activities shifted toward issuing private sector companies leases to establish plantations within forest reserves. This shift in activities and management appears to have resulted in significantly different plantation failure rates:

- 2001-2009: "Survey and Mapping of Government Plantation Sites Established between 2004 and 2009 in some Forest Reserves of Ghana" stated that 44.9% of the planted area was estimated to have failed during this time period.
- 2010-2012: The NFPDP 2013 Dataset on Final Verification Nationwide included estimates of survival percentage per forest reserve.
- 2013: Data for 2013 included average survival percentage of 75.43%, and thus a failure rate of 24.6% was applied.
- Due to a lack of data for the years 2014 and 2015, the area planted for 2014 and 2015 is the average adjusted total for the years 2010-2013.

The adjusted annual estimates for area planted were then divided according to species composition, so that appropriate removal factors could be applied. The total estimated area of successful plantations was assumed to be comprised of 70% teak species and 30% other broadleaf species. This assumption about species composition was made based on expert opinion as well as a review of NFPDP data.

3.7.2 Removal Factors

Removal factors represent the long-term average standing carbon stocks over the lifetime of each species, per hectare (i.e., half the maximum carbon stocks). Specific removal factors for both teak and other broadleaf species were developed based on published studies that offered regionally appropriate estimates of the carbon stocks in these two types of plantations.

For teak plantations, the study conducted by Adu-Bredu S., et al. 2008[26] tree carbon stocks in teak stands in different ecological zones in Ghana was used to develop removal factors. For teak species planted in forest reserves located within the Ghana Cocoa Forest REDD+ Program (GCFRP) area, the estimated carbon stocks for teak stands in the 'Moist Evergreen Forest' ecological zone was applied: 97.69 Mg C ha^{-1} (includes both above and belowground tree carbon stocks). For teak stands outside the GCFRP area, the carbon stocks for teak stands in the 'Savannah' ecological zone was applied: 26.09 Mg C ha^{-1} (includes both above and belowground tree carbon stocks).

[26]Adu-Bredu S., et al. (2008). Carbon Stock under Four Land-Use Systems in Three Varied Ecological Zones in Ghana. Proceedings of the Open Science Conference on Africa and Carbon Cycle: the CarboAfrica project, Accra, Ghana, 25-27 November 2008. Available at http://www.fao.org/3/a-I2240.pdf

The long-term average carbon stock of the teak stands over multiple cycles was assumed to be half the total carbon value for carbon stocks in each ecological zone and final removal factors in t CO_2/ha were calculated by applying the molecular weight ratio of carbon dioxide to carbon, of 44/12 to get 179 t CO_2/ha for teak stands in the GCFRP area and 48 t CO_2/ha for teak stands outside the GCFRP area.

Non-teak broadleaf species:

Due to a lack of data available on carbon stocks in tree plantations in Ghana, IPCC AFOLU Vol. 4 default values from table 4.8 reflecting aboveground biomass in forest plantations were applied. Values for 'Africa broadleaf >20 years' for three ecological zones in Ghana (tropical rain forest, tropical moist deciduous forest, and tropical dry forest) were averaged to get 173.3 t d.m. ha-1, which was converted to t C/ha by applying a factor of 0.5 to get 87 t C/ha. The belowground biomass value was then generated by applying a root-to-shoot ratio of 0.235 for tropical/subtropical moist forest/plantations >125 Mg ha^{-1} (Mokany et al.2006), to get 20 t C/ha. The total aboveground biomass in non-teak broadleaf species was thus estimated to be the sum of below and above-ground biomass stocks: 107 t C/ha.

The long-term average carbon stock of the non-teak broadleaf species stands over multiple cycles was assumed to be half the total carbon value (53.5 Mg C ha^{-1}).

The final removal factor in t CO2/ha was calculated by applying the molecular weight ratio of carbon dioxide to carbon, of 44/12 to get 196 t CO_2/ha.

Removal factors are summarized in the table 8 below, but more comprehensively elaborated in Annex A.

Table 8. Removal Factors

Species	Ecological Zone	Long-Term Stocks t CO_2/ha	Source
Teak	GCFRP Area (Moist Evergreen Forest)	179	Adu-Bredu S., et al. 2008
Teak	Non GCFRP Area (Savannah)	48	Adu-Bredu S., et al. 2008
Non-teak	All	196	IPCC AFOLU Vol. 4 table 4.8

By applying committed removals, the impact of this activity are only accounted for once, in the year the plantation was established. The removal factors listed below represent the long-term average carbon stock accumulation of the tree plantation over several cycles.

Under this approach, removals are discounted to account for incidence of plantation failure in the activity data for removals.

HISTORICAL EMISSIONS RESULTS

The annual emissions and removals defined in the FL are estimated according to the following equation:

$$FREL = (CDefor_{REL} + CDegrad_{REL\,(LTH)} + CDegrad_{REL\,(ITH)} + CDegrad_{REL\,(F)} + CDegrad_{REL\,(FW)} + CRefor_{REL})$$

Where:

$FREL$	Projected annual emissions and removals from the forest sector summed across all strata; t CO_2-e/yr
$CDefor_{REL}$	Predicted annual emissions from deforestation in each stratum; t CO_2-e/yr
$CDegrad_{REL\,(LTH)}$	Predicted annual emissions from forest degradation on forestland remaining forestland from legal timber harvest; t CO_2-e/yr
$CDegrad_{REL\,(ITH)}$	Predicted annual emissions from forest degradation on forestland remaining forestland from illegal timber harvest; t CO_2-e/yr
$CDegrad_{REL\,(F)}$	Predicted annual emissions from forest degradation on forestland remaining forestland from fire; t CO_2-e/yr
$CDegrad_{REL\,(FW)}$	Predicted annual emissions from forest degradation on forestland remaining forestland from woodfuel; t CO_2-e/yr

$CEnhanc_{REL}$	Predicted annual emissions from afforestation and reforestation; note net removals from the atmosphere are depicted by a negative sign; t CO_2-e/yr

The annual average emissions for the 15-year period between 2000-2015 from deforestation was 41.1 million tCO_2e. Emissions were highest from the moist evergreen ecozone, which accounted for 28% of the total emissions nationally (Figure 7).

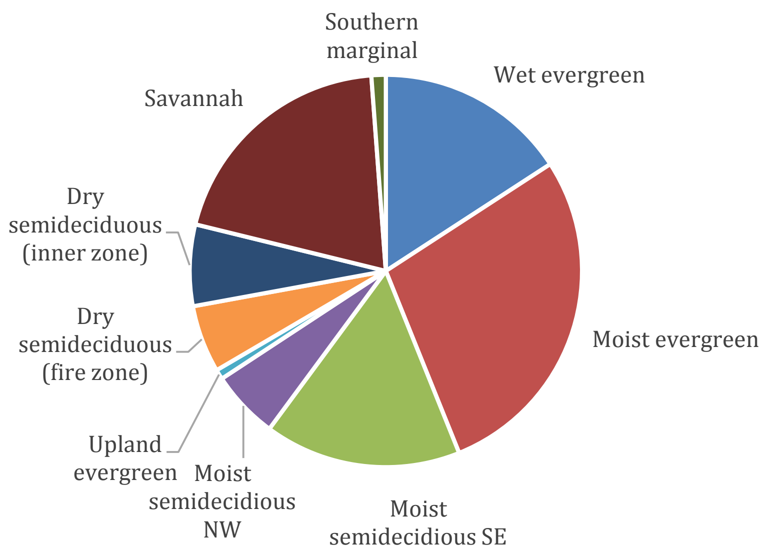


Figure 7. Relative emissions from deforestation by ecozone

4.1 Emissions from deforestation

The annual average emissions for the 15-year period from 2000 to 2015 from deforestation was 40.0 million tCO_2e (Table 9). Emissions from deforestation appear to increase significantly between the years 2013 and 2015.

Emissions were highest from the moist evergreen ecozone, which accounted for 28% of the national total (Figure 8). The GCFRP area makes up 67% of the national deforestation emissions, while 33% come from elsewhere in the country.

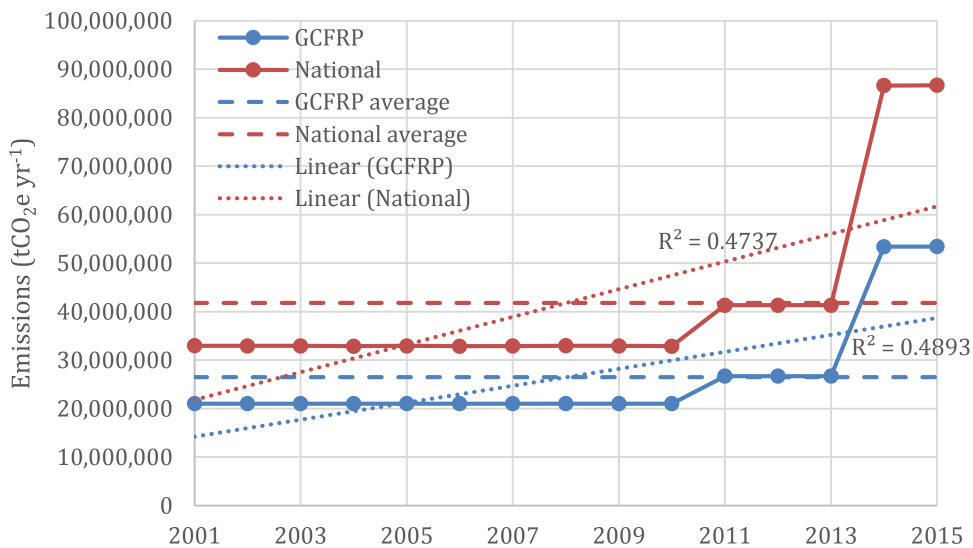


Figure 8. Historical emissions from deforestation, showing average and trends for both the GCFRP and the entire country.

Table 9. Emissions from deforestation for Ghana between 2000 – 2015.

Ecozone	Forest structure	Annual area deforested (ha)	Annual Emissions (tCO_2 yr^{-1})	Non-CO_2 gas emissions from fire (tCO_2e yr^{-1})	Total Emissions from deforestation (tCO_2e yr^{-1})
Wet evergreen	*Closed forest*	10,810	4,621,636	0	4,621,636
	Open forest	11,022	1,865,630	0	1,865,630
Moist evergreen	*Closed forest*	14,162	7,327,264	4	7,327,268
	Open forest	36,544	4,183,889	0	4,183,889

Moist semi-decidious SE	*Closed forest*	12,238	5,079,048	770	5,079,818
	Open forest	23,140	1,565,953	768	1,566,721
Moist semi-decidious NW	*Closed forest*	7,153	574,516	90	574,606
	Open forest	22,026	1,730,270	4,020	1,734,290
Upland evergreen	*Closed forest*	687	149,113	0	149,113
	Open forest	586	182,471	0	182,471
Dry semi-deciduous (fire zone)	*Closed forest*	2,867	231,364	1,275	232,639
	Open forest	18,381	2,030,358	14,815	2,045,174
Dry semi-deciduous (inner zone)	*Closed forest*	1,371	322,460	322	322,782
	Open forest	16,407	2,423,407	3,582	2,426,988
Savannah	*Closed forest*	3,313	169,470	1,607	171,077
	Open forest	135,555	7,995,389	29,139	8,024,528
Southern marginal	*Closed forest*	218	34,007	0	34,007
	Open forest	4,323	450,339	79	450,417

Total GCFRP		138,368	27,279,790	5,652	27,285,442
Total rest of country		182,435	13,656,794	50,819	13,707,613
Total country		320,803	40,936,584	56,471	40,993,055

4.2 Emissions from degradation from timber harvest

4.2.1 Emissions from legal timber harvest

The annual average emissions over a 15-year period between 2000-2015 from legal logging was 3.6Mt CO_2e between 2000-2015. In general, emissions were higher at the beginning of the reference period, with 2002 having the highest amount of emissions (5.1 M t CO_2e). After a sharp decrease between 2002 and 2004 emissions fluctuate near the FRL average before a short spike in 2013 of roughly 3.8 M tCO_2e. In 2014 and 20015 emissions decreased steadily (see Figure 10).

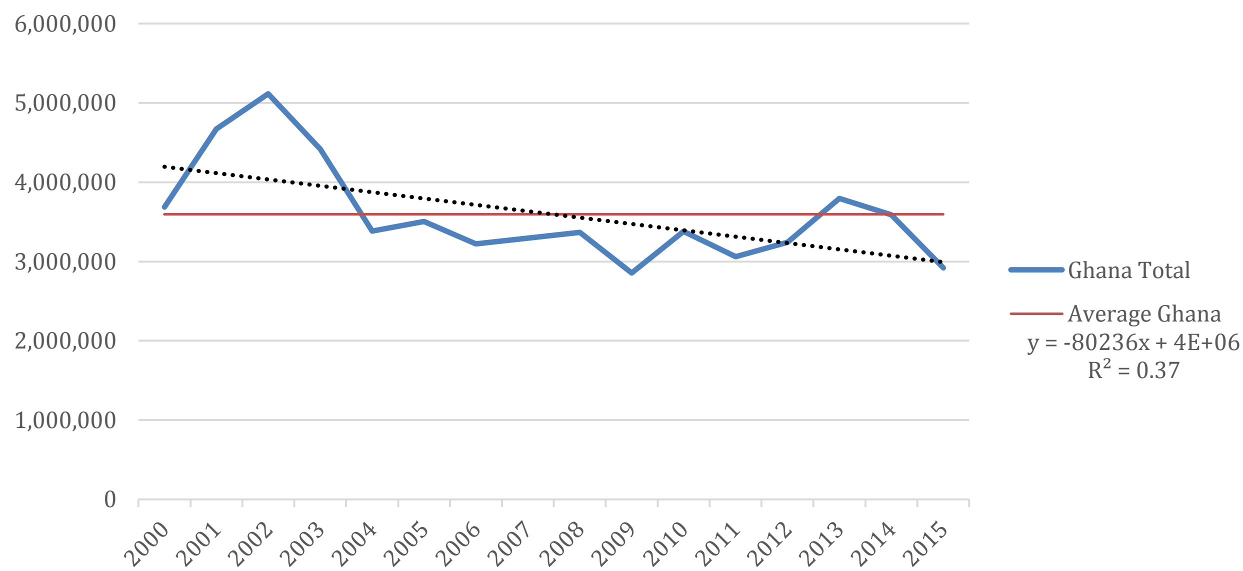


Figure 10. Historical emissions from legal timber harvest between 2000-2015.

4.2.2 Illegal timber harvest

The annual average emissions from illegal logging over a 15-year period from 2000-2015 were 13.4 M tCO_2e.

4.3 Emissions from wood fuel

Using the data for woodfuel from 2009 as a proxy for the average emissions from woodfuel over the reference period the average annual emission between 2000 and 2015 were 899,499 tCO_2e. The areas with greatest emissions come from the more populated regions of Greater Accra (1M t CO_2/yr) and the Ashanti region (almost 700 thousand t CO_2/yr). The location reflects where the fuelwood is consumed although some of the emissions will have occurred at the site where the fuelwood is harvested, which in many cases may differ (for example fuelwood harvested in northern Ghana are mainly transported to Accra).

Table 10. national emissions from woodfuel

Region	Emissions t CO_2/yr
Greater Accra	1,055,287
Ashanti	669,895
Brong Ahafo	142,533
Central	284,955
Eastern	332,542
Northern	209,971
Volta	274,263
Upper East	295,332
Upper West	64,704
Western	163,488
Total	**3,492,970**

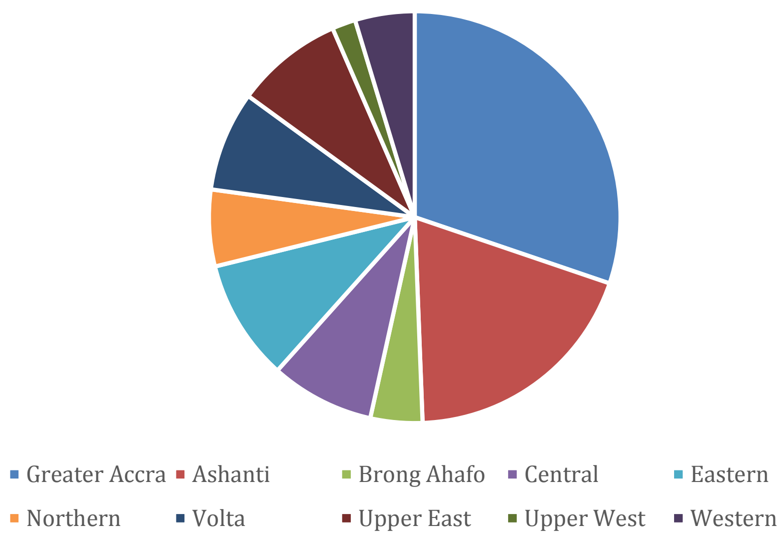


Figure 11. Proportion of national fuelwood emissions per region

4.4 Emissions from degradation from fire

The annual average emissions from forest fire between 2001-2015 were 0.7 million tCO_2e. In general, emissions were higher in the first half of the reference period, with 2001 having the highest amount of emissions (Figure 12). Emissions were highest from the savannah ecozone (Figure 13).

Figure 12. Yearly emissions due to forest fire during the reference period

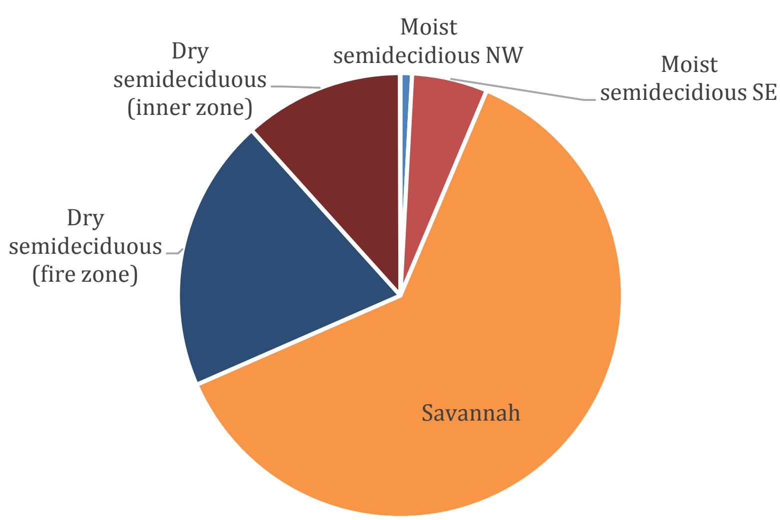


Figure 13. Relative emissions from forest fire in the nine ecozones

4.5 Removals from enhancement of carbon stocks

The annual removals from plantations on forest reserves nationally during the reference period were approximately 610 thousand t $CO_2e.yr^{-1}$, with removals peaking at roughly 985,500 t $CO_2e.yr^{-1}$ between 2005 and 2009 after which they decrease considerably in 2010 to 219,350 t $CO_2e.yr^{-1}$. This drop coincides with a major shift within the NFPDP in 2009 when many plantation programs ceased (MTS, CFMP, GPDP, and Model).

As previously noted, under the 'committed removals approach' the sequestration and dates reflect the date of tree planting rather than the true date at which sequestration occurs.

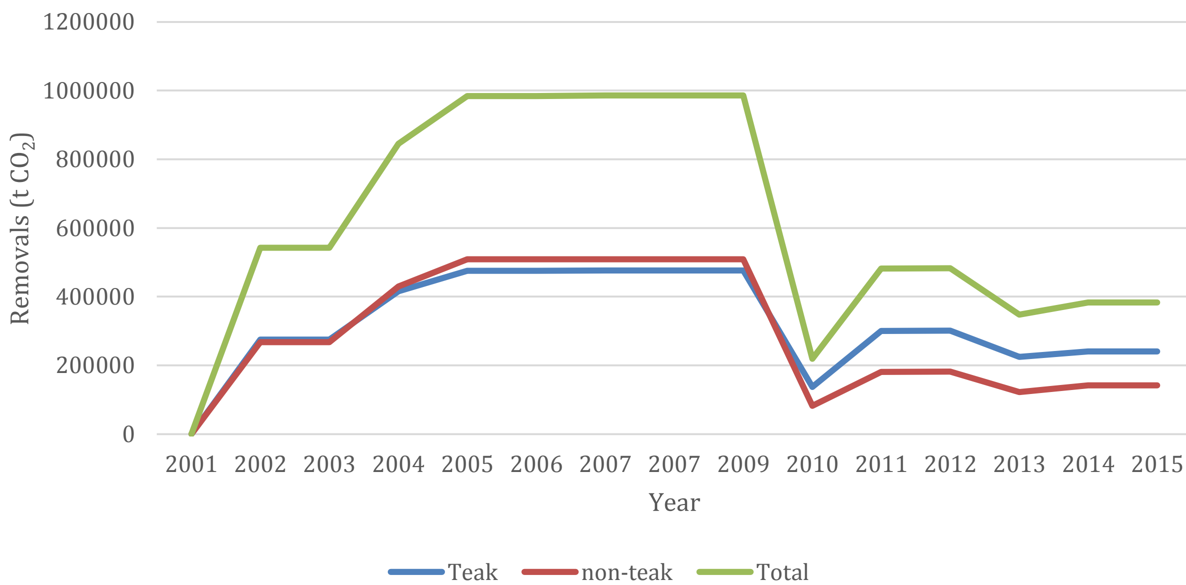
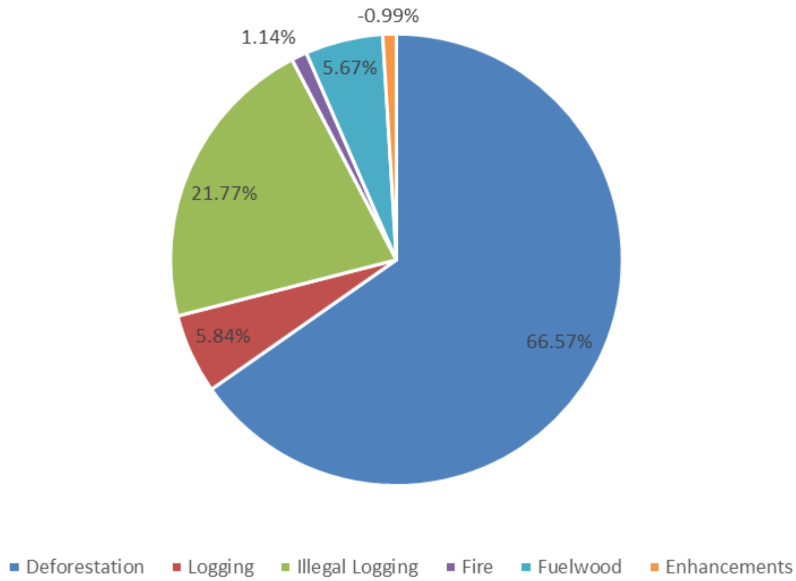


Figure 14. Historic national removals in $tCO_2e.yr^{-1}$ with the numbers reflecting committed sequestration at the date of planting

4.6 Total Emissions

When summed, the average annual emissions from 2000-2015 were 61.6 million tCO_2e yr^{-1} and the average annual removals were 610 thousand t CO_2e yr^{-1}. Over sixty-six percent of emissions were due to deforestation, while legal and illegal logging made up 28% combined. Fuelwood and forest fire accounted for a minimal percentage of total emissions, making up just 6% and 1% respectively (Figure 15).



4.7 Uncertainty

4.7.1 Identification and assessment of sources of uncertainty

The key sources of uncertainty are identified below and summed across emission/removal factors and activity data (within strata). Summation of errors follows the propagation of errors approach described in equations 3.1 and 3.2 of the IPCC (2006) (equations 3 and 4 respectively). Errors were weighted and propagated for parameters with the same units of measurement. For parameters and uncertainty assumption, see annex A.

Figure 35 Relative emissions from each REDD+ activity

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

Eq. 3 (Eq. 3.1 of the IPCC (2006))

Where:

U_{total} = percentage uncertainty of the product of quantities (half the 90% confidence interval, divided by the total and expressed as a percentage);

U_i = percentage uncertainty associated with each of the quantities.

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

Eq. 4 (Eq. 3.2 of the IPCC (2006))

Where:

U_{total} = percentage uncertainty of the sum of quantities (half the 95% confidence interval, divided by the total (i.e. the median) and expressed as a percentage). The term "uncertainty" is based on the 95% confidence interval

x_i y U_i = absolute uncertainty and associated percentage uncertainties, respectively.

Details of analyses are given in the accompanying spreadsheets named National Emissions and Removals Calculation Tool.

4.7.2 Quantification of uncertainty in FRL setting

Details of uncertainty quantification methods are given under the relevant section for each activity in Annex A. Summation of uncertainties used the propagation of error approach with weighting.

Table 11. Uncertainty per activity

Activity	Uncertainty
Deforestation	5.5%
Legal Timber Harvest	5.7%
Illegal Timber Harvest	53.0%
Woodfuel	50.0%
Fire	21.7%
Enhancement	24.9%
Total	12.1%

Total uncertainty for the FRL is 12.1% (uncertainty as a percentage of the mean). This is predominantly determined by the dominance of emissions from deforestation (66%).

4.7.3 How uncertainties will be reduced

Uncertainty in deforestation emissions are low and cannot be meaningfully reduced further through MRV changes. However, further work in the future, will include assessment of activity data with confusion matrices and updating of emission factors with field data collection.

Uncertainty in legal timber harvest is equally low through excellent field data collection by the Forestry Commission and activity data through national statistics.

In contrast, the uncertainty in illegal logging emissions is high due to the use of proxy. This uncertainty shouldbe reduced through the development of a specific monitoring program to capture annual activity data from illegal logging.

Fuelwood emissions, are also highly uncertain, predominantly because they result from an analysis at a single point in time. Uncertainty will be reduced through implementation of the MRV plans.

Fire emissions are on par with those from from fuelwood (just 5 % of total emissions). As such the 23% uncertainty is considered reasonable.

Uncertainty in sequestration will be reduced through implementation of the MRV system and in particular with the development of country-specific removal factors for non-teak tree plantations.

FOREST REFERENCE LEVEL

5.1 Overview of potential options for creating FRLs

Among the international community, the following options for projections have been discussed as being applicable for national and subnational FRL: (1) historical average, (2) continuation of the historical trend and (3) adjusted to national (subnational) circumstances.

The **average FRL** is set as continuation of historical average, which can have different implication for countries or provinces. Countries or provinces with rapidly increasing emissions from deforestation will have difficulties to achieve deep emission cuts necessary to maintain their historical average, while countries or provinces with historically decreasing emissions will achieve their emissions cuts with fewer efforts.

The **continuation of historical trend FRL** requires assessment of the historical data for presence of a statistical trend. Countries with increasing emissions will project increasing trend for the RL, while countries with decreasing historical emissions will project decreasing trend for RL, making the cuts in emissions for both scenarios more affordable.

The **adjusted for national (subnational) circumstances FRL** requires more detailed analysis and justification that the historical drivers of deforestation and forest degradation are expected to change in the future that will result in an increase of emissions. However, for most countries an upward adjustment may be difficult to justify and will likely affect only those countries that have high forest cover and historically low rates of deforestation and emissions.

Following the Carbon Fund Methodological Framework[27] developed by the World Bank Forest Carbon Partnership Facility (FCPF), Ghana's GCFRP Emission Reduction Program was submitted as an average FRL.

5.2 Proposed National Forest Reference Level

The historical annual emissions show a significant increasing trend for deforestation in particular (see section 4.1), which is the largest source of emissions for Ghana. Emissions from deforestation increase substantially from 2013 to 2015. As such, Ghana proposes establishing a national FRL based on a trend instead of an average of emissions as it more accurately captures the anticipated behaviour of emissions from REDD+ activities based on increasing emissions in the latter years of the reference period.

The trend was calculated by examining activities separately. A clear upward trend in emissions exists for deforestation and a downward trend in emissions from legal logging (Figure 16). For all other activities no trend exists and the average was taken.

[27] Published for review on September, 5, 2013
https://www.forestcarbonpartnership.org/sites/fcp/files/2013/Dec2013/FCPF%20Carbon%20Fund%20Meth%20Framework%20-%20Final%20December%2020%202013%20posted%20Dec%2023rd.pdf

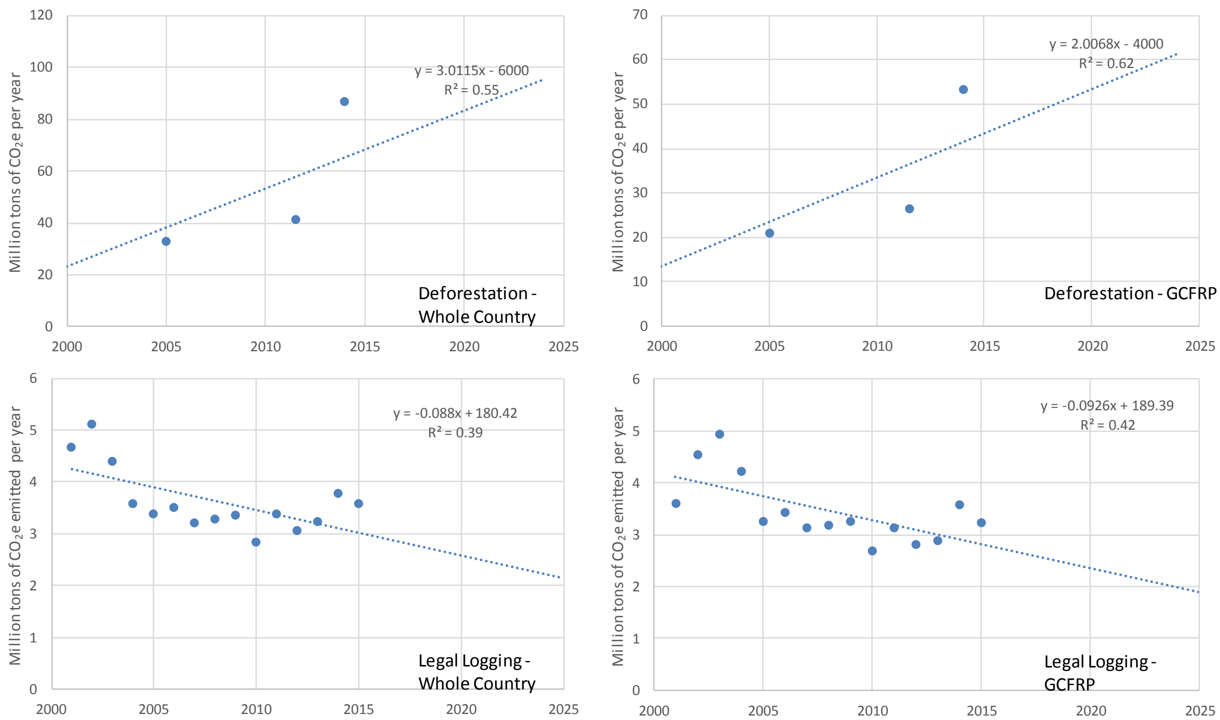


Figure 46. Trends in emissions across the reference period for deforestation and legal logging for summed national emissions and for the GCFRP

The actual and projected emissions for the National reference level and GCFRP are shown in Table 12 and Figure 17.

Table 12. Reference period and projected reference level for GCFRP and national areas.

Emissions and removals ($tCO_2e\ yr^{-1}$)		
	GCFRP	National
REFERENCE PERIOD		
2001	38,988,641	55,500,725
2002	39,638,745	55,424,123
2003	40,069,410	54,919,489
2004	39,232,831	52,879,689
2005	38,239,291	53,103,862
2006	38,394,009	52,958,922
2007	38,181,619	52,787,415
2008	38,308,556	53,443,730
2009	38,418,696	53,406,155
2010	37,871,143	52,990,747
2011	43,784,214	61,442,871
2012	43,479,954	61,120,441
2013	43,809,512	61,711,364
2014	71,014,009	107,033,516
2015	70,703,053	107,096,925
PROJECTION		
2016	62,486,785	91,059,007
2017	64,400,996	93,982,466
2018	66,315,207	96,905,924
2019	68,229,418	99,829,383
2020	70,143,629	102,752,841
2021	72,057,840	105,676,300
2022	73,972,051	108,599,758
2023	75,886,262	111,523,217
2024	77,800,473	114,446,675
2025	79,714,684	117,370,134

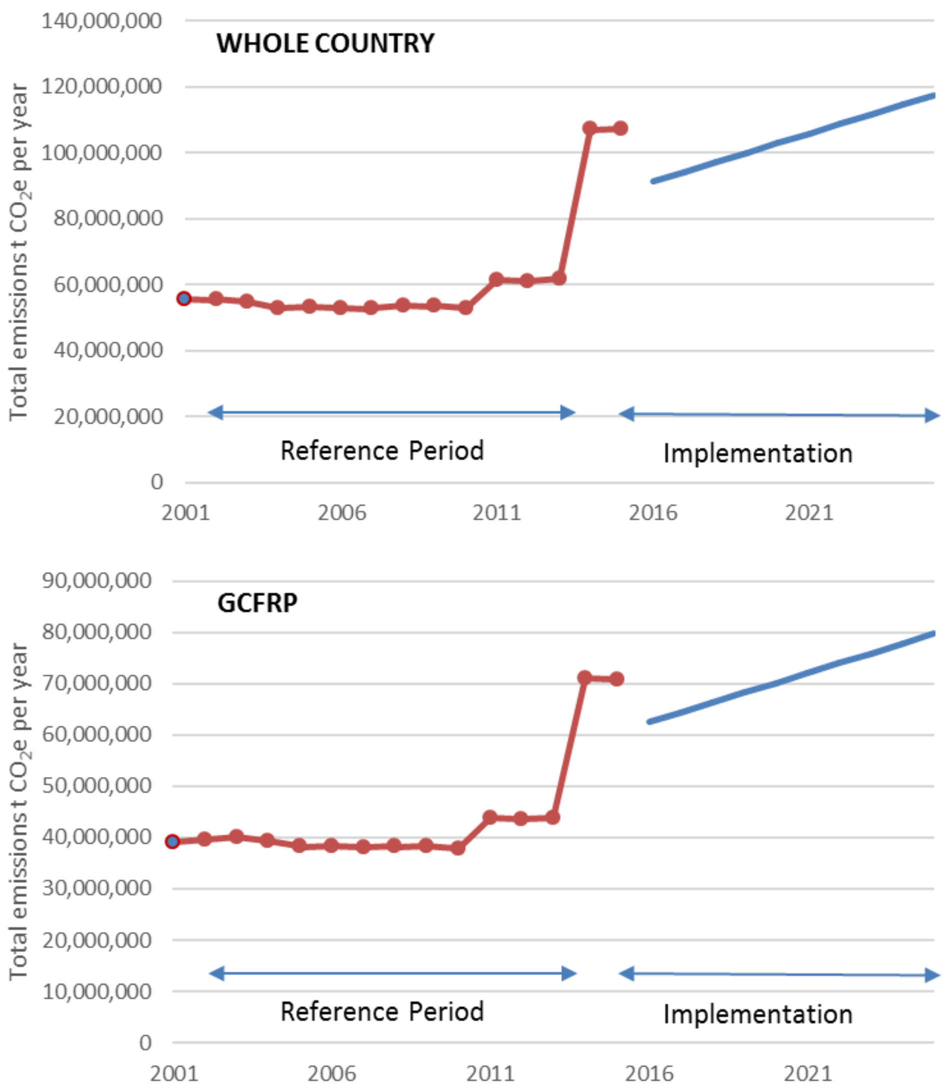


Figure 17 Historical and Projected Emissions

The national trend line can be described mathematically as:

$$y = 3E{+}06x + 4E{+}07$$

The GCFRP trend line can be described mathematically as:

$$y = 2E{+}06x + 3E{+}07$$

6. STEPWISE IMPROVEMENTS

6.1 Deforestation

Activity data for deforestation will continue to be updated biennually to comply with UNFCCC-recommended reporting norms. Land cover maps will continue to rely on Landsat imagery, although future maps will use Landsat 8 imagery rather than Landsat 7. Images from other sources will be considered, especially radar-derived products such as PALSAR that avoid the issue of cloud cover, which is a common problem in Ghana. Pre-processing and classification will be standardized in the future to ensure greater compatibility between maps for more accurate change detection, and a standard country mask will be used to ensure accurate mapping along Ghana's borders.

Research will be conducted on post-deforestation carbon stocks within Ghana to replace the literature-based stocks used in this FRL. This will allow for more accurate emission factors by better quantifying the growth of non-forest land cover types after deforestation events.

6.2 Carbon stock Enhancements

A centralized, comprehensive database of carbon stock enhancements undertaken under the NFPDP would represent a stepwise improvement of measurement and monitoring for this activity. The database would maintain the following data on carbon stock enhancement activities needed for accurate measurement and monitoring of this REDD+ activity under the ER program:

- **Spatial data on annual area planted under NFPDP funding**. This would include shapefiles of planted areas;
- **Verified area planted;**
- **Species composition; and**
- **Estimated plantation survival rates**:
  - Data collected in field surveys to verify area planted and estimate survival rate (within the year planting occurred)
  - Ongoing performance of planted area through assessment of a sample of all on-reserve planted areas using Google Earth

6.3 Timber Harvesting

6.3.1 Legal Timber Harvesting

The main improvement necessary for legal timber harvest is to improve the logging infrastructure factor (LIF) estimate. This can be done by correlating the measurements taken in the fieldwork undertaken in May 2016 by the Forestry Commission with timber extracted for those specific locations.

6.3.2 Illegal Timber Harvesting

Given the nature of this activity, it is difficult to gather comprehensive estimate of total timber extracted from illegal practices. However, it will be important to develop a systematic approach to assess the impact of this activity on the ER-Programs' total emissions.

The AD used for the FRL provides an estimate of timber volume for the year 2009 based on the methodology used by Hansen et al. 2012. While this estimate provides a useful proxy for the FRL, the study has not been replicated to date.

The Forestry Commission has begun gathering data on illegal logged timber based on what rangers at the district level confiscate from illegal loggers. These data exist for 2013-2015 and so could be a source of data for monitoring illegal timber harvesting in the future. However, it should be noted that these data are based on what rangers are able to confiscate from forest reserves andthus represent only a portion of the actual illegally logged timber. Furthermore, at this stage, it is understood that these data remain incomplete, even within the forestry reserves.

Incentives should be provided to rangers and other staff of the Forestry Commission to encourage a significant increase in monitoring at the scale of the GCFRP Hotspot Intervention Areas (HIAs), using the reporting methods developed by RMSC. These data can be aggregated at the FSD's District Manager level and reported back to RMSC.

The other option is to follow the methods outlined in Hansen et al 2012 and conduct a similar study, systematically to establish estimates every two years.

6.4 Woodfuel Collection

While the analysis of emissions from historic woodfuel collection generated for the development of the national FRL represents what can be considered an IPCC Tier 2 approach (see Bailis et al. 2015[28]), there are opportunities for stepwise improvements to the emission estimates by integrating more spatially explicit or country-specific data inputs to the WISDOM model. Furthermore, the emissions estimated for the FRL represent those for the year 2009, and thus updated data to apply to the WISDOM model will be necessary for tracking emissions during the MRV period.

The following suggestions for updating and improving WISDOM estimates for Ghana were developed in association with Rudi Drigo, the co-author of the WISDOM model. Stepwise improvements could be made both in the data applied to the WISDOM model, along with the development of in-country capacity for applying the model. Updates to estimated emissions from woodfuel use would be necessary for monitoring emissions from this activity.

The WISDOM model can be tailored to fit Ghana's needs in terms of geographic scope, and consists of modules on demand, supply, integration and woodshed analysis. Each module requires different competencies and data sources and its contents are determined by the data available or, to a limited extent, by the data purposively collected to fill critical data gaps. Information of relevance to wood energy comes from multiple sources, ranging from census data to local pilot studies or survey data.

Demand:

Woodfuel demand is largely a function of population and population density, infrastructure, household energy supply needs, and access to woodsheds.As such, the following sources of data can support the estimation of woodfuel demand specifically for Ghana and its ecozones:

- Population census
- Spatial data on infrastructure (e.g., roads, gas pipelines)
- Topography
- Surveys of household energy needs and use

[28] http://www.nature.com/nclimate/journal/v5/n3/full/nclimate2491.html?message-global=remove

Supply:

Woodfuel supply is a measure of both the existing biomass in woodsheds as well as their productivity. Productivity is an important consideration as it accounts for the ability of biomass stocks to regenerate once harvested for woodfuel use).

The following sources can contribute to the estimation of woodfuel supply in Ghana:

- Biomass Stocks (stocks could be tailored to match FPP data)
- Productivity (mean annual increment)

Integration

Use of spatial data to estimate the demand and supply balance of woodfuel, specific to the desired spatial resolution. This will identify areas of deficit, surplus, and can help plan for future scenarios.

Woodshed analysis

The analysis for the delineation of woodsheds in Ghana, i.e. supply zones of specific consumption sites requires additional analytical steps that may be summarized as:

- Mapping of potential "commercial" woodfuel supplies suitable for urban, peri-urban and rural markets.
- Definition of woodsheds, or woodfuel harvesting areas, based on the level of commercial and non-commercial demand, woodfuels production potentials and physical/economic accessibility parameters. Estimation of harvesting sustainability, of woodfuel-related fNRB values at subnational level and of woodfuel induce forest degradation rates.

6.5 Forest fire

Although the MODIS burned area product will continue to be used in the short term, more accurate, higher-resolution alternative activity data sources will be researched for long term use. These could include a Landsat-based burned area product or higher-resolution data sources. This higher-resolution option would allow for more accurate detection of small degradation fires that likely go undetected by MODIS. Research will be performed to calibrate such burned area products to Ghana specifically instead of using global algorithms.

Research will also be conducted to provide more accurate, ecozone-level combustion factors to improve the emissions estimations from fire.

ANNEX A: METHODOLOGIES FOR ESTIMATING EMISSIONS AND REMOVALS AND UNCERTAINTY ANALYSIS

Methods

Deforestation

Emission Factors

In accordance with the stock-difference[29] method, C emissions were estimated as the difference in carbon stocks before deforestation and the carbon stocks following deforestation, including carbon in living and dead biomass[30] and carbon released from the soil. The emission factor is calculated as follows:

$$EF_{def(t,x,y)} = (C_{bio.pre(x)} - C_{bio.post(t,y)} + \Delta SOC_{(t)}) * 44/12$$

Where:

$EF_{def(t,x,y)}$ = Emission factor for year t for deforestation for stratum *x* and driver *y*, $tCO_2e\ ha^{-1}$

$C_{bio.pre(x)}$ = Carbon stock in biomass in stratum *x,* prior to deforestation, $t\ C\ ha^{-1}$

$C_{bio.post(t,y)}$ = Carbon stock in biomass in year t post-deforestation, for driver *y*, $t\ C\ ha^{-1}$

$\Delta SOC_{(t)}$ = Change in soil carbon stocks in year t following deforestation, $t\ C\ ha^{-1}$

44/12 = Conversion factor from carbon to CO_2

Pre-deforestation carbon stocks include all carbon pools (aboveground carbon, belowground carbon, deadwood, litter, non-tree vegetation, and soil). Estimates of the magnitude of carbon stocks in these pools were mostly derived from the results of a forest biomass mapping and inventory project undertaken through the Mapping of Forest Cover and Carbon Stock in Ghana

[29] 2006 AFOLU Guidelines, Chapter 2 Generic Methodologies Applicable to Multiple Land-Use Categories, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf

[30]For Ghana's reference level for deforestation emissions,carbon stored in harvested wood products was not included

project (conducted under the Forest Preservation Programme (FPP), through support from the Government of Japan).

The only carbon pool for which FPP data were not used for pre-deforestation carbon stocks was the deadwood carbon pool, as stocks appeared to be significantly over estimated[31]. Instead, IPCC defaults were applied for this pool (aboveground carbon stocks multiplied by 0.06)

The Wet Evergreen, Open Forest stratum did not have data on belowground carbon stocks, so the Mokany (2006) root-to-shoot ratio of 0.2 was applied to the aboveground carbon stocks to derive an estimate.

Pre-deforestation carbon stocks were calculated as follows:

$$C_{bio.pre(x)} = (C_{agb(x)}+C_{bgb(x)}+C_{dw(x)}+C_{lit(x)}+C_{veg(x)})$$

Where:

$C_{bio.pre(x)}$ = Carbon stock in biomass in stratum *x,* prior to deforestation, t C ha^{-1}

$C_{agb(x)}$ = Carbon stock in aboveground live tree biomass in stratum *x*, t C ha^{-1}

$C_{bgb(x)}$ = Carbon stock in belowground live tree biomass in stratum *x*, t C ha^{-1}

$C_{dw(x)}$ = Carbon stock in deadwood pools in stratum *x*, t C ha^{-1} (includes both standing and lying deadwood)

$C_{lit(x)}$ = Carbon stock in litter in stratum *x*, t C ha^{-1}

$C_{veg(x)}$ = Carbon stock in non-tree vegetation in stratum *x*, t C ha^{-1} (includes shrubs, sapling, and herbaceous understory)

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[31]This was explained in the FPP Report on Mapping of Forest Cover and Carbon Stock in Ghana (2013) pp.128: "Deadwood in large quantities was discovered in moist evergreen plots, most like due to trees felled on the cocoa farms admitted to expand into the forest reserves and palm pruning residues of palm trees in off-reserve areas." Nevertheless, when plot deadwood carbon pool estimates were extrapolated to per-hectare values were unrealistically high (e.g. Moist Evergreen Closed Forest 2914 t CO_2/ha and Moist Semi-deciduous NW Closed forest 399 t CO_2/ha - over double the aboveground tree biomass).

Applied Pre-Deforestation Carbon Stocks:

Confidence interval (95% of the mean +/- %) noted in parenthesis.

		AGB (tC/ha)	BGB (tC/ha)	Dead Wood Carbon Stocks (tC/ha)[32]	Litter Carbon Stocks (tC/ha)	Non-tree Carbon Stocks (tC/ha)	Total C stocks (not soil) tC/ha
Wet Evergreen	Closed Forest	124.1 (0.7)	7.9 (108.0)	7.4	2.7 (32.0)	0.0 (N/A)	142.2
	Open Forest	30.3 (2.3)	6.1 (N/A)	1.8	0.0 (N/A)	0.0 (N/A)	38.1
Moist Evergreen	Closed Forest	139.4 (0.2)	23.5 (28.0)	8.4	2.7 (33.0)	0.5 (40.0)	174.5
	Open Forest	39.8 (0.8)	3.0 (48.0)	2.4	1.1 (192.0)	1.6 (773.0)	47.9
Moist Semideciduous SE	Closed Forest	123.5 (0.6)	23.2 (23.2)	7.4	0.0 (46.0)	1.1 (63.0)	155.2
	Open Forest	35.2 (1.4)	7.6 (171.0)	2.1	3.5 (55.0)	0.3 (250.0)	48.7
Moist Semideciduous NW	Closed Forest	40.4 (0.2)	15.3 (12.0)	2.4	2.2 (23.0)	1.1 (23.0)	61.3
	Open Forest	17.5 (0.3)	9.0 (31.0)	1.0	2.2 (50.0)	0.8 (50.0)	30.5
Upland Evergreen	Closed Forest	73.1 (0.4)	23.5 (99.0)	4.4	1.4 (36.0)	0.3 (279.0)	102.6

	Open Forest	26.2 (0.8)	12.8 (47.0)	1.6	1.1 (67.0)	0.8 (173.0)	42.5
Dry Semideciduous Inner Zone	Closed Forest	23.2 (5)	14.7 (N/A)	1.4	1.4 (5.0)	2.2 (8)	42.85
	Open Forest	14.2 (0.8)	10.1 (24.0)	0.9	1.19 (47.0)	2.2 (57.0)	29.2
Dry Semideciduous Fire Zone	Closed Forest	15.3 (3.5)	0.0 (N/A)	0.9	0.0 (N/A)	0.0 (N/A)	16.19
	Open Forest	12 (0.5)	7.9 (N/A)	0.7	1.6 (N/A)	0.8 (N/A)	23.1
Savannah	Closed Forest	17.7 (1.3)	0.0 (N/A)	1.06	0.0 (N/A)	0.0 (N/A)	18.79
	Open Forest	13.1 (0.5)	4.6 (57.0)	0.8	1.6 (26.0)	0.55 (58.0)	20.69
Southern Marginal	Closed Forest	11.18 (3.7)	16.91 (27.0)	0.67	2.18 (123.0)	0.55 (279.0)	31.49
	Open Forest	8.45 (2.7)	6.82 (55.0)	0.51	0.55 (108.0)	0.82 (661.0)	17.14

[32] No uncertainty is provided in brackets for this pool as it was calculated as a proportion of the AGB pool, in accordance with IPCC methods.

Post-deforestation carbon stocks correspond to the land uses comprised of IPCC land use classes (forest land, cropland, grassland, wetlands, settlement, bare land, other land), and their carbon stocks were derived from a combination of sources including:

1) Cropland: Given the complex set of post-deforestation land uses found in Ghana, particularly due to the wide range of agricultural land uses, the 'cropland' post-deforestation land use was subdivided into:

   a) Cropland: The FPP project collected data on cropland carbon stocks for each stratum, reflecting all cropland (currently cropped or in fallow), rice fields, and agro-forestry systems. Estimates included above and belowground carbon stocks (other carbon pools in cropland are not considered significant), and post-deforestation carbon stocks were calculated as follows:

$$C_{bio.post(y,t)} = (C_{agb(y)} + C_{bgb(y,t)})$$

Where:

$C_{bio.post(y,t)}$ = Carbon stock in biomass in land use y at time t, post-deforestation, t C ha^{-1}

$C_{agb(y)}$ = Carbon stock in aboveground live tree biomass in land use y, t C ha^{-1}

$C_{bgb(y,t)}$ = Carbon stock in belowground live tree biomass in land use y at time t[33], t C ha^{-1}

   b) Plantations: Carbon stocks in plantations were treated as a time-weighted average of stocks in the cycle, and were sourced from Konsager et al. (2013)[34]'s study of carbon stock accumulation potential of tree plantations in Ghana. The values for plantation carbon stocks represent time-averaged carbon stocks for a 30-year rotation, based on the results of that study, as cited in a presentation by the same author.

20. The study only estimates aboveground carbon stocks, so belowground carbon stocks were derived by applying Mokany (2006) root-to-shoot ratio of 0.2 for tropical moist semi-deciduous forest with aboveground biomass stocks <125 t d.m. ha.

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[33] If roots remain following deforestation, pre-deforestation belowground carbon stocks are assumed to decompose over 10 years. Therefore post-deforestation below-ground carbon stocks are estimated as $C_{bgb(x,t-1)} - (C_{bgb(x)}/10)$, where t equals years following deforestation.

[34] Konsager et al. The carbon sequestration potential of tree crop plantations. Mitigation Adaptation Strategies for Global Change (2013) 18:1197–1213. Time-averaged results from http://orbit.dtu.dk/files/55883745/Carbon_Sequestration.pdf

2) Grassland: FPP data were applied where available per strata, otherwise the IPCC default of 3.1 t C/ha was applied.
3) Wetlands: Assumed to be zero
4) Settlement: FPP data were applied where available per strata, otherwise post-deforestation carbon stocks were assumed to be zero.
5) Bareland/other: Assumed to be zero

Applied Post-Deforestation Carbon Stocks:

Stratum	Stratum			Average Carbon stocks (tC/ha)	Source
Wet Evergreen					
	Cropland	Cropland		25	FPP data
		Plantations	Oil Palm	36	Kongsager et al. 2013
			Citrus	55	Kongsager et al. 2013
			Rubber	90	Kongsager et al. 2013
			Cocoa	55	Kongsager et al. 2013
	Grassland			3.1	IPCC Grasslands Table 3.4.2 value for tropical moist & wet
	Wetlands			0	
	settlement			0	
	Bareland/other			0	
Moist Evergreen	Cropland	Cropland		36	FPP data
		Plantations	Oil Palm	36	Kongsager et al. 2013
			Citrus	55	Kongsager et al. 2013
			Rubber	90	Kongsager et al. 2013
			Cocoa	55	Kongsager et al. 2013
	Grassland			0.0	FPP data
	Wetlands			0	
	settlement			0	
	Bareland/other			0	
Moist Semidecid uous SE	Cropland	Cropland		46	FPP data
		Plantations	Oil Palm	36	Kongsager et al. 2013

			Citrus	55	Kongsager et al. 2013
			Rubber	90	Kongsager et al. 2013
			Cocoa	55	Kongsager et al. 2013
	Grassland			3.1	IPCC Grasslands Table 3.4.2 value for tropical moist & wet
	Wetlands			0	
	settlement			0.00	
	Bareland/other			0	
Moist Semidecid uous NW	Cropland	Cropland		28	FPP data
		Plantations	Oil Palm	36	Kongsager et al. 2013
			Citrus	55	Kongsager et al. 2013
			Rubber	90	Kongsager et al. 2013
			Cocoa	55	Kongsager et al. 2013
	Grassland			3.27	FPP data
	Wetlands			0	
	settlement			2.18	FPP data
	Bareland/other			0	
Upland evergreen	Cropland	Cropland		31	FPP data
		Plantations	Oil Palm	36	Kongsager et al. 2013
			Citrus	55	Kongsager et al. 2013
			Rubber	90	Kongsager et al. 2013
			Cocoa	55	Kongsager et al. 2013
	Grassland			3.1	IPCC Grasslands Table 3.4.2 value for tropical moist & wet
	Wetlands			0	
	settlement			0	
	Bareland/other			0	
Dry semidecid uous Inner	Cropland	Cropland		14	FPP data
		Plantations	Oil Palm	36	Kongsager et al. 2013
			Citrus	55	Kongsager et al. 2013
			Rubber	90	Kongsager et al. 2013
			Cocoa	55	Kongsager et al. 2013

	Grassland			3.1	IPCC Grasslands Table 3.4.2 value for tropical moist & wet
	Wetlands			0	
	settlement			0.00	
	Bareland/other			0	
Dry semidecid uous Fire	Cropland	Cropland		13	FPP data
		Plantations	Oil Palm	36	Kongsager et al. 2013
			Citrus	55	Kongsager et al. 2013
			Rubber	90	Kongsager et al. 2013
			Cocoa	55	Kongsager et al. 2013
	Grassland			1.36	FPP data
	Wetlands			0	
	settlement			0	
	Bareland/other			0	
Savannah	Cropland	Cropland		12	FPP data
		Plantations	Oil Palm	36	Kongsager et al. 2013
			Citrus	55	Kongsager et al. 2013
			Rubber	90	Kongsager et al. 2013
			Cocoa	55	Kongsager et al. 2013
	Grassland			15.82	FPP data
	Wetlands			0	
	settlement			0	
	Bareland/other			0	
Southern Marginal	Cropland	Cropland		9	FPP data
		Plantations	Oil Palm	36	Kongsager et al. 2013
			Citrus	55	Kongsager et al. 2013
			Rubber	90	Kongsager et al. 2013
			Cocoa	55	Kongsager et al. 2013
	Grassland			6.82	FPP data
	Wetlands			0	
	settlement			0	
	Bareland/other			0	

Changes in soil carbon stocks are related to the post deforestation land use and were estimated using the IPCC 2006 guidelines whereby changes in soil carbon stocks are based on the use of soil factors that account for how the soil is tilled, the method of management, and inputs in the post deforestation land use. This method is described through the following equation:

$$\Delta SOC = C_{soil} - (C_{soil} * F_{LU} * F_{MG} * F_I)$$

Where:

ΔSOC = Soil carbon emitted, t C ha^{-1}

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

F_{LU} = Stock change factor for land-use systems for a particular land-use, dimensionless (IPCC AFOLU GL)

F_{MG} = Stock change factor for management regime, dimensionless (IPCC AFOLU GL)

F_I = Stock change factor for input of organic matter, dimensionless (IPCC AFOLU GL)

The change in soil carbon stocks is assumed to occur over a 20-year time period, but for simplicity in accounting emissions are considered to be committed and to occur at the time of conversion.

The following factors and assumptions were made for each strata:

- CROPLAND: Applied Table 5.10 in 2006 IPCC Guidelines FLU value for shifting cultivation, shortened fallow based on FAO Country Paper on Ghana, "Shifting cultivation (also known as "slash and burn") is the main farming practice in Ghana, ... land is left to fallow for some time (3 - 5 years, depending on the availability of land for farming."[35]
    - FLU: Long-term cultivated Tropical moist =0.48
    - FMG: reduced tropical moist/wet = 1.15
    - FI: Medium, dry and moist/wet = 1.0
- PLANTATIONS: Plantations assigned following factors:
    - FLU: Long-term perennial tree crops = 1.0

[35] M. O. Abebrese, 2002. ROPICAL SECONDARY FOREST MANAGEMENT IN AFRICA:Reality and perspectives, Ghana Country Paper. Available at: http://www.fao.org/docrep/006/j0628e/j0628e53.htm

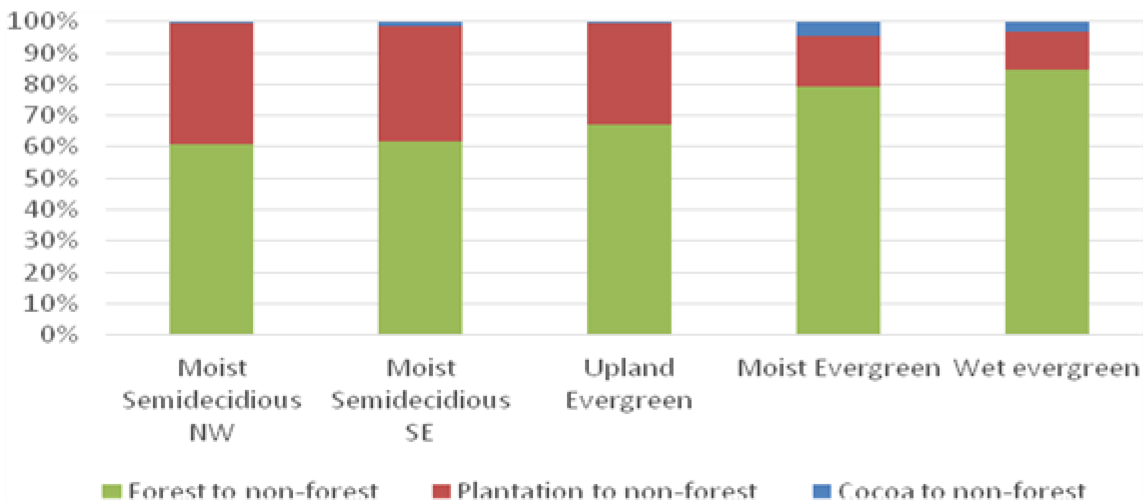
    - FMG: No till, tropical, moist/wet = 1.22
    - FI: Medium, dry and moist/wet = 1.0
- GRASSLAND: IPCC Table 6.2, FMG: Moderately degraded grassland
- WETLANDS: As seen from activity data, the areas converted to wetlands over the reference period were along the coast, so it was assumed this was due to flooding. As such, zero emissions were assumed.
- SETTLEMENT: From IPCC Chapter 8, "for the proportion of the settlement area that is paved over, assume product of FLU, FMG and FI is 0.8 times the corresponding product for the previous land use (i.e., 20% of the soil carbon relative to the previous land use will be lost as a result of disturbance, removal or relocation);"
- BARELAND/OTHER: “Other Land” includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five land-use categories. Assumed to be land devoid of vegetation and likely to be at some point in a cropping cycle. Therefore, the same values for cropland were applied.
    - FLU: Long-term cultivated Tropical moist = 0.48
    - FMG: reduced tropical moist/wet = 1.15
    - FI: Medium, dry and moist/wet = 1.0

Activity Data

Activity data for deforestation consisted of four land cover maps for the years 2000, 2010, 2013, and 2015. All maps used Landsat 7 and 8 images, with the 2010 map using ALOS images in addition to Landsat images. For the 2010 map, efforts were made to harmonize it with the 2000 map to ensure comparability and change calculation. The 2000 and 2010 maps were produced during the FPP project, while the later maps were produced in 2016 by the RMSC of the Ghana Forestry Commission. Due to the difficulty of mapping differences between open forest, grassland and cropland in Ghana using an automated classification software, these maps will continue to be refined using a stepwise approach. Some of the issues that will continue to be addressed in the reference period maps include:

- The 2015 map has very high level of open forest all over the country. There is a huge shift from grasslands to open forest between 2012 and 2015 that could complicate accounting in the future.
- In the 2013 map, there are some areas in water bodies that have grassland pixels in the middle of the lakes. Although not large areas, it would be useful to revise the water body extents to ensure consistency with previous maps.
- There are large areas in the Upper East region in the 2013 map that appear to change drastically from the 2010 map, mostly confusion between cropland, grassland and open forest. This may be due to seasonal differences in imagery dates.

Due to the similarity in the spectral signature of agricultural tree crops, especially cocoa, rubber, oil palm and citrus, in the cocoa growing area the land cover maps were not able to distinguish these non-forest plantations from natural forestlands. For this reason, a high-resolution remote sensing methodology was applied (as described in Annex B), to determine the proportion of the mapped forest that is actually agricultural tree plantations. This analysis was able to distinguish areas of forestland, cocoa, plantation (which included rubber, oil palm, and citrus), and other non-plantation and non-forest land cover types. The results showed that of the areas mapped as deforestation in the land cover maps, between 1-4% were actually transition of cocoa to non-plantation non-forest types, and between 12-39% were actually transition of plantation to non-plantation non-forest types, depending on the ecozone (Figure A1). Emissions from deforestation were subsequently reduced by the percentage of mapped deforestation that was determined to actually be movement of agricultural tree plantations to non-plantation non-forest land cover types.



A1. Result of high resolution analysis, showing percentage of areas classified as deforestation that were actually transition of agricultural tree plantations to non-plantation non-forest land cover types.

The high resolution analysis was also applied to determine the percentage of area classified as forest remaining forest in the land cover maps that was actually forest transitioning to agricultural tree plantations (and thus qualifying as deforestation). Results showed that of all the classes that the land cover maps classified as forest remaining forest, forest to cocoa made up between 12-18% and forest to plantation made up between 2-5% (Figure A2). Emissions from deforestation were subsequently increased by the percentage of mapped forest remaining forest that was determined to actually be deforestation resulting from movement of forest to agricultural tree plantations.

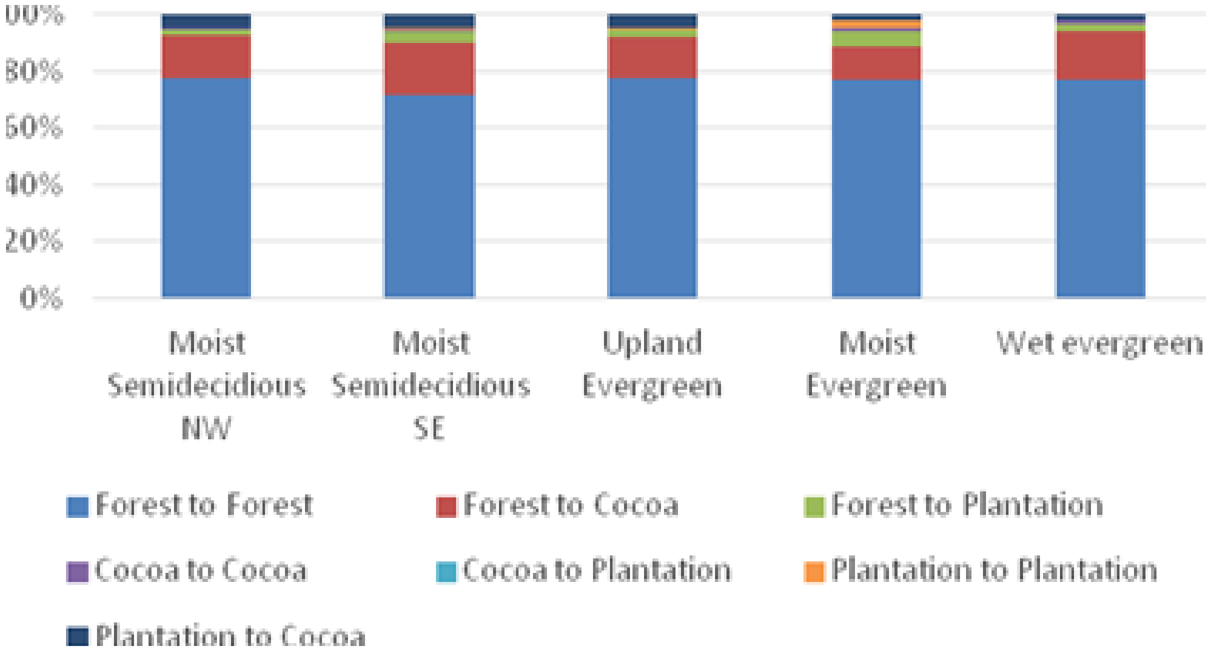


Figure A2. Result of high-resolution analysis, showing percentage of areas classified as forest remaining forest that were actually transition of forestland to agricultural tree plantations.

Enhancement

Removal Factors

Teak:

The study conducted by Adu-Bredu S., et al. 2008[36] assessing tree carbon stocks in teak stands in moist evergreen forest in Ghana was used to develop removal factors for teak stands in Ghana. The value of 97.69 Mg C ha^{-1} included both above and belowground tree carbon stocks. The long-term average carbon stock of the teak stands over multiple cycles was assumed to be half the total carbon value (49 Mg C ha^{-1}).

The final removal factor in t CO_2/ha was calculated by applying the molecular weight ratio of carbon dioxide to carbon, of 44/12 to get 179 t CO_2/ha.

[36] Adu-Bredu S., et al. (2008). Carbon Stock under Four Land-Use Systems in Three Varied Ecological Zones in Ghana. Proceedings of the Open Science Conference on Africa and Carbon Cycle: the CarboAfrica project, Accra, Ghana, 25-27 November 2008. Available at http://www.fao.org/3/a-I2240.pdf

Non-teak broadleaf species:

Due to a lack of data available on carbon stocks in tree plantations in Ghana, IPCC AFOLU Vol. 4 default values from table 4.8 reflecting aboveground biomass in forest plantations were applied. Values for 'Africa broadleaf >20 years' for three ecological zones in Ghana (tropical rain forest, tropical moist deciduous forest, and tropical dry forest) were averaged to get 173.3 t d.m. ha-1, which was converted to t C/ha by applying a factor of 0.5 to get 86.7 t C/ha. The belowground biomass value was then generated by applying a root-to-shoot ratio of 0.235 for tropical/subtropical moist forest/plantations >125 Mg ha^{-1} (Mokany et al.2006), to get 20.36 t C/ha. The total aboveground biomass in non-teak broadleaf species was thus estimated to be the sum of below and above-ground biomass stocks: 107.01 t C/ha.

The long-term average carbon stock of the non-teak broadleaf species stands over multiple cycles was assumed to be half the total carbon value (53.5 Mg C ha^{-1}).

The final removal factor in t CO2/ha was calculated by applying the molecular weight ratio of carbon dioxide to carbon, of 44/12 to get 196.19 t CO_2/ha.

The values and sources used to estimate for both removal factors are summarized below:

Species		Value	Unit	Source
Teak, GCFRP Area [37]	AGB & BGB	98	Mg C ha	Adu-Bredu S., et al. 2008
	Long-term stocks	49	Mg C ha	
	Final RF	180	t CO_2/ha	
Teak, outside GCFRP Area[38]	AGB & BGB	26	Mg C ha	Adu-Bredu S., et al. 2008
	Long-term stocks	13	Mg C ha	
	Final RF	48	t CO_2/ha	

[37] Value for Moist Evergreen Forests
[38] Value for Savannah

Species		Value	Unit	Source
Non-teak broadleaf	AGB	173	t d.m. ha-1	IPCC AFOLU Vol. 4 table 4.8 above-ground biomass in forest plantations.
		87	Mg C ha	
	BGB	20	Mg C ha	Mokany et al.2006
		107		
	Long-term stocks	54		
	Final RF	196	t CO_2/ha	

Activity Data

Activity data were derived from official records of NFPDP activity, which document hectares of on-reserve planting by reserve. Spatial layers of the GCFRP area and forest reserves were combined to calculate removals occurring only in on-reserve plantations within the GCFRP. Where forest reserves fell on the boundary of the GCFRP area, activity data were divided according to the percentage that fell within the GCFRP border.

For both GCFRP and National estimates of removals from enhancement activities, a number of adjustments and assumptions were made to accommodate data gaps and limitations.

- While the NFPDP was launched in September 2001, records reflect planting only began in 2002. As such, there were zero activity data for 2001.
- No activity data were available for the years 2014 and 2015, and thus the average rate of on-reserve planting from 2010-2013 was applied. This time period was selected as it was deemed most representative of the plantation activities undertaken during 2014 and 2015, due to the fact that many of the plantation programs in previous years (MTS, CFMP, GPDP, and Model) ceased in 2009.
- Complete annual data on plantation activity for MTS, CFMP, GPDP, and Model programs were not available (i.e., in some cases, multi-year totals were only provided). As such, the total area planted in Ghana forest reserves up to 2009 was divided across the years the program was in operation to get annual activity data.
- The estimated annual rates were then adjusted to account for plantation failure, which was necessary given the 'committed removals' approach taken (discussed further in section 3.7). The plantation failure rates which were used to adjust annual totals were derived from GFC reports and other national data, and are summarized below.

- **Failure rate 2001-2009**: 44.9% (Source: Survey and Mapping of Government Plantation Sites Established Between 2004 to 2009 in Some Forest Reserves in Ghana)
- **Failure rate 2010-2012:** 24.57 % (Source: NFPDP dataset '2013 Final Verification Nationwide'. Calculated based on the average survival rate recorded.)
- Actual estimates for rates of survival per forest reserve were available for the year 2013, so activity data for 2013 were not adjusted. As discussed above, the area planted for 2014 and 2015 is the average adjusted total for the years 2010-2013.

- With the exception of 2013 data, the records did not include information on species composition. As such, it was assumed that 70% of the planted species were teak and the other 30% were other mixed species.

Adjusted Annual Area Planted Totals for Reference Period National															
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
GPDP	0	0	0	5003	5003	5003	5003	5003	5003	0	0	0	0		
MTS	0	8246	8246	8246	8246	8246	8246	8246	8246	0	0	0	0		
CFMP	0	0	0	0	2432	2432	2432	2432	2432	0	0	0	0		
Model	0	0	0	0	0	0	20	20	20	0	0	0	0		
Total	0	8246	8246	13249	15681	15681	15701	15701	15701	1852	4085	4092	2083		
With failure rate applied	0	4544	4544	7300	8640	8640	8651	8651	8651	1397	3081	3086	2083	2412	2412

NFPDP Programs	Dates of Operation	Years
GPDP	2004-2009	6
MTS	2002-2009	8
CFMP	2005-2009	5
Model	2007-2009	3
Other (Private Developers & Expanded Program)	2001-2015	6

Legal Timber Harvesting

The calculations of total emissions from logging are a result of a multiplication of total emission factor (TEF) (in t $CO2.m^{-3}$) by the activity data (m^3 extracted) for each year.

Activity Data

Ghana has timber extracted data for the entire historical period 2010-2015. These data present the total volumes of timber extracted annually by species and by administrative unit (region and locality) based on the Tree Information Forms (TIFs). With the exception of 2000 and 2015, this data is summed annually across administrative units to calculate total volumes by areas of interest. Only half of the volumes extracted for 2000 and 2015 were used, so that the reference period does not exceed 15 years in total, so not to ensure consistency with the time period reported for Ghana's FCPF Emission Reduction Program.

Emission Factors

The three components of the logging emission factor were calculated using the methods in Pearson et al. (2014) and using field measurements taken by the Ghana Forestry Commission following the standard operating procedures in Annex C. This method accounts separately for three emission sources that occur as a result of logging:

1. emissions from the subsequent milling, processing, use and disposal of the felled timber-tree,
2. emissions from incidental damage caused by the timber-tree fall and cutting of the log in the forest, and
3. emissions from infrastructure associated with removing the timber out of the forest (e.g. skid trails, logging decks and logging roads).

All emissions sources are associated with the volume of timber extracted (e.g. m^3) to allow for simple application of timber harvesting statistics. As such, the total emission factor from selective logging is estimated as the sum of three factors:

$$TEF = ELE + LDF + LIF$$

Where:

TEF Total emission factor ($tCO2.m^{-3}$)

ELE Emissions from extracted log ($tCO2.m^{-3}$)

LDF Logging damage factor ($tCO2.m^{-3}$)

LIF Logging infrastructure factor ($t CO2.m^{-3}$)

A committed emissions approach is employed in the calculations to simplify the carbon accounting process. This means that all emissions are accounted in the year of the logging event.

To estimate ELE, an average wood density (in g cm-3) weighted by the volume extracted of each species from the activity data is calculated, so that the average wood density (and therefore ELE) would reflect the species most harvested in Ghana. The applied wood density of 0.39 t/m^3 was calculated as the weighted mean of harvested species from the database of legally harvested trees between 2000 and 2015. The chainsaw milling efficiency applied is 50% as identified by the Forestry Commission and through literature revue (Hansen et al, 2012). The ELE reflects the proportion of carbon dioxide still sequestered in harvested wood products 100 years after initial harvest (considered to be permanently sequestered). A half-life of 30 years and a decay rate of 0.023 are applied as given in Table 12.2 in IPCC 2006[39].

Estimate for LDF are based on the measurements taken from the field work conducted by Ghana FC in May 2016, using the SOPs in annex C.

For skid trails it was assumed that creation of trails would avoid trees with a diameter greater than 20cm at breast height. The proportion of forest biomass represented by trees less than 20cm was calculated from the dataset of Napier and Kongsager (2011).[40] Across ten plots these trees represented 12% of the forest biomass (95% CI = 4.8%). This proportion was applied to the carbon stock derived from the FPP inventory dataset.

From measurement of 164 skid trails by the Ghana Forestry Commission in May 2016, the mean width was 4.6m (95% CI = 0.64m). For five skid trails the associated extraction volume was determined, and through integration with trail length a skid trail emission factor was derived.

For logging roads, the mean width was calculated from 11 roads measured by the Ghana Forestry Commission in May 2016 (5.3m +/- 0.65; mean +/- 95% CI). A per length of road emission was calculated from this width and the carbon stock from the FPP inventory dataset. However, no volumes could be paired with emission per length of road. This correlation instead had to rely on the

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[39] IPCC (2006) Guidelines for national greenhouse gas inventories. Volume 4: Agriculture, Forestry, and Other Land Use. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

[40]Napier, J. and Kongsager R. (2011). The breakeven price of REDD-credits: a case study from Kade, Ghana. Master Thesis, Technical University of Denmark.

study of Medjibe et al (2013) from Gabon.[41] Medjibe et al determined road construction of 1 m per cubic meter of log extracted.

For logging decks volume correlations were similarly unavailable. The Medjibe et al study determined logging decks represent 1.6 square meters of area per cubic meter of log extracted. This paired with FPP inventory data produced a decks emission factor.

Illegal Timber Harvest

The calculations of total emissions from illegal logging will mirror those used for legal logging with the multiplication of total emission factor (TEF) (in tCO2 m^{-3}) by the activity data (m^3 extracted).

Activity Data

Yearly activity data on the amount of timber harvested illegally in Ghana are not available. However, a number of studies have been conducted that provide estimates on the amount of illegal timber harvest. We will use the estimates from of one of these studies - 'Revisiting Illegal Logging and the Size of the Domestic Timber Market (Hansen et al. 2012).[42]Hansen estimated illegal logged timber at 4.1 million m^3 per year.

Emission Factor

The emission factor for illegal timber harvest follow the same methodology as for legal timber harvest. The measurements taken in the field in May 2016 by the Forestry Commission were used to estimate TEF for illegal as well as legal timber harvest. As for legal logging a committed emissions approach is taken.

The extracted log emissions (ELE) were calculated with the following assumptions:

- The species harvested reflect the same species distribution as species legally harvested in Ghana;
- The logs are chainsaw milled in the forest;
- The resulting products are solidwood products.

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[41]Medjibe, V.P., Putz, F.E., Romero, C. (2013) Certified and uncertified logging concessions compared in Gabon: Changes in stand structure, tree species, and biomass. Environmental Management. DOI 10.1007/s00267-012-0006-4

[42]Hansen, C.P., L. Damnyag, B.D. Obiri and K. Carlsen 2012. Revisiting illegal logging and the size of the domestic timber market: the case of Ghana International Forestry Review Vol.14(1), 2012 39

Based on the findings of Hansen et al. (2012) the chainsaw milling efficiency applied is 27%. The applied wood density of 0.39 t/m^3 was calculated as the weighted mean of harvested species from the database of legally harvested trees between 2000 and 2015. The ELE reflects the proportion of carbon dioxide still sequestered in harvested wood products 100 years after initial harvest (considered to be permanently sequestered). A half-life of 30 years and a decay rate of 0.023 are applied as given in Table 12.2 in IPCC 2006[43].

Based on an understanding of illegal timber practices by the Forestry Commission, LDF is assumed to be identical to the factor used for legal timber harvesting.

LIF is assumed to be nullified as illegal timber harvested either use infrastructure created by legal timber harvesting practices.

Degradation from Fire

Total emissions from forest fire calculated using Equation 2.27 from IPCC (2006)[44]:

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

Where:

L_{fire}= amount of greenhouse gas emissions from fire, tonnes of each GHG

A = area burnt, ha

M_B= mass of fuel available for combustion tonnes ha-1

C_f= combustion factor, dimensionless

G_{ef}= emission factor, g kg^{-1} dry matter burnt

Activity Data

The activity data represents the total area burnt during the reference period. The MODIS Burned Area Product was used, which gives monthly totals of burned area at the 500m scale across the globe. The following steps were taken to process this data for the reference period:

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[43] IPCC (2006) Guidelines for national greenhouse gas inventories. Volume 4: Agriculture, Forestry, and Other Land Use. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

[44] IPCC (2006) Guidelines for national greenhouse gas inventories. Volume 4: Agriculture, Forestry, and Other Land Use. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

- Clip the global dataset to Ghana.
- Combine the monthly burned area pixels to create yearly burned area maps, from 2001-2015 (2000 was not included to maintain a 15-year reference level).
- Divide burned area between areas of forest remaining forest between 2000-2015 and areas of deforestation, both according to Ghana's national land cover maps. Burned area on all other land cover types was discarded. This was done to differentiate between forest fires that result in degradation and fires that result in deforestation, since deforestation fires will be accounted for separately.

The high-resolution analysis (described in Annex B) was used to determine the percentage of fires, mapped as deforestation fires, were actually fires occurring on agricultural tree plantations transitioning to non-plantation non-forest lands. A proportion of deforestation fires were removed from deforestation accounting corresponding to this percentage. The high-resolution analysis was also used to determine the proportion of fires, mapped as degradation fires, were actually on areas of: 1) agricultural tree plantations remaining plantations (and thus neither degradation nor deforestation fires), and 2) forest transitioning to agricultural tree plantations (and thus being deforestation fires). A proportion of deforestation fires were removed for degradation accounting corresponding to the percentages of these areas (and a proportion was added to the deforestation accounting).

Emission Factors

There are three parameters that make up the emission factor: the biomass available for combustion (M_B), the combustion factor (C_f), and the emission factor (G_{ef}).

Biomass available for combustion

The biomass available for combustion refers to all the biomass in the forest that is subject to burning by fire. Generally, only part of the overall biomass in the forest is subject to burning. The carbon pools that are subject to burning depend on the fire regime in the area; if surface fires are common, generally only the pools close to the forest floor are included (litter, deadwood, shrubs, grasses, small trees, and topsoil organic carbon). If canopy fires are common, a greater proportion of the larger trees may be available for combustion as well.

For this FRL, it was assumed that all forest biomass was subject to burning. This assumption was made due to the nature of the activity data from the MODIS burned area product. The burned area product generally detects only larger fires, given that it is a satellite product viewing primarily the forest canopy, has a spatial resolution of 500m. Therefore, fires must kill relatively large sections of the canopy in order to be detected by MODIS, and it is assumed that if the canopy is being burned, the understory biomass is also subject to burning.

For areas that burned in multiple years, a reduced biomass available for burning value was used, which was equal to the original biomass multiplied by the combustion factor and by the number times the area had burned. For example, if an area burned for the second time in specific year, the original biomass was multiplied by the combustion factor and by 2.

Combustion factors

Combustion factors refer to the fraction of M_B that is actually combusted during fire. C_f depends largely on climate and ecosystem, since combustion will be more complete under dry, hot conditions. Defaults from IPCC[45] were used since country-level data was not available.

Emission Factors

Emission factors in Equation 2.27 refer to the amount of each GHG that is emitted when a certain amount of dry matter is burned. The reference level accounts for the major GHGs emitted during biomass burning, which are CO_2, N_2O, and CH_4. Since these emission factors are fairly constant across forest types, IPCC (2006) defaults from Table 2.5 were used for G_{ef}.

Parameter Tables and Uncertainty Details

Deforestation

[45] Factors from Table 2.6 of IPCC (2006)

Activity Data

Description of the parameter including the time period covered (e.g. forest-cover change between 2000 – 2005 or transitions between forest categories X and Y between 2003-2006):	Landsat imagery classified using NDVI. Forest cover change between 2000-2010-2013-2015. Stratified between "open" and "closed" forest, within five ecological zones (wet evergreen, moist evergreen, moist semi-deciduous SE, moist semi-deciduous NW, upland evergreen).
Explanation for which sources or sinks the parameter is used (e.g deforestation or forest degradation):	Deforestation
Data unit (e.g. ha/yr):	Average ha/yr
Source of data (e.g. official statistics) or description of the method for developing the data, including (pre-)processing methods for data derived from remote sensing images (including the type of sensors and the details of the images used):	Land cover maps developed by the Forest Preservation Programme (FPP) project for 2000 and 2010[46]; remote sensing analysis conducted by RMSC for 2013 and 2015, Applied Geo-Solutions (AGS) remote sensing analysis on differentiating natural forest from tree crops (see Annex C).

[46] Forest Preservation Project. 2013. Report on Mapping of Forest Cover and Carbon Stock in Ghana. Executed by PASCO Corporation, Japan in collaboration with FC-RMSC, CSIR-FORIG and CIRT-SRI, Ghana

Discussion of key uncertainties for this parameter:	For the 2000 and 2010 images, accuracy assessment was completed on the 2010 land cover map using verification data from 2,213 field locations all across Ghana. Once the 2010 map was well established (as good an accuracy as could be produced within resource constraints) the same land cover classification methods were applied to 2000 land cover map. The 2012 and 2015 maps were produced replicating the same methodology, to the extent possible, that was used for the 2000 and 2010 maps. Key uncertainties include error in remote sensing classification due to haze, cloud cover, stripping from a Landsat 7 satellite malfunction, differences in seasonal greenness, and reflectance differences between Landsat images.
Estimation of accuracy, precision, and/or confidence level, as applicable and an explanation of assumptions/methodology in the estimation:	2000/2010: The classification of forest to non-forest is 84% Accurate based on 2,213 field location across the country. No accuracy assessment has been conducted on the 2012/2015 maps, this will be included in the ER-PD during the review process when completed. At this point it is assumed that accuracy of these later maps is the same as for the 2000/2010 maps.

Table 2-10: Accuracy Assessment Result of LU Map of 2010

Classified data \ Reference data	Forest land	Cropland	Grassland	Settlements	Wetlands	Other land	Classified Total	Users Accuracy (%)
Forestland	520	48	39	0	0	0	**607**	85.67
Cropland	57	493	48	1	0	2	**601**	82.03
Grassland	55	44	384	0	0	9	**492**	78.05
Settlements	17	13	12	283	1	5	**331**	85.50
Wetlends	0	0	1	0	152	0	**153**	99.35
Otherland	2	0	3	0	0	24	**29**	82.76
Reference Total	**651**	**598**	**487**	**284**	**153**	**40**	**2213**	-
Producer Accuracy (%)	79.88	82.44	78.85	99.65	99.35	60.00	-	**83.87**

Emission Factors

Description of the parameter including the	Difference in carbon stocks (pre and post deforestation land cover) per stratum. Strata were identified through the Forest Preservation Programme (FPP) Mapping

forest class if applicable:	of Forest Cover and Carbon Stock in Ghana project. and represent all relevant IPCC land cover classes. **Carbon pools:** Pre-deforestation land use stocks: Aboveground biomass, belowground biomass, deadwood, litter, non-tree vegetation, soil carbon stocks. Data on carbon pools were sourced from the FPP Mapping of Forest Cover and Carbon Stock in Ghana project. Post-deforestation land use carbon stocks: • Cropland: ○ Herbaceous and shifting cultivation: Aboveground biomass, belowground biomass, deadwood, litter, non-tree vegetation, soil carbon stocks. Data on carbon pools were sourced from the FPP Mapping of Forest Cover and Carbon Stock in Ghana project. ○ Plantations: Aboveground biomass and belowground biomass (other carbon stocks conservatively omitted). Aboveground biomass values sourced from Konsager et al. (2013)[47] and belowground biomass stocks were determined by applying a root-to-shoot ratio developed by Mokany et al. (2006)[48] . Grassland[49]: aboveground biomass. Values derived either from the FPP Mapping of Forest Cover and Carbon Stock in Ghana project or IPCC default values. Wetlands, settlement[50], Water and bareland/other: carbon stocks assumed to be zero.
Data unit (e.g. t CO_2/ha):	t CO_2e/ha
Source of data (e.g. official statistics, IPCC, scientific literature) or	Pre-deforestation carbon stocks: • Data were derived from the Forest Preservation Programme (FPP) which conducted the Mapping of Forest Cover and Carbon Stock in Ghana project. Data from this project offered estimates of all forest carbon pools, including soil.

[47] Konsager et al. The carbon sequestration potential of tree crop plantations. Mitigation Adaptation Strategies for Global Change (2013) 18:1197–1213. Time-averaged results from http://orbit.dtu.dk/files/55883745/Carbon_Sequestration.pdf

[48] Mokany K, Raison R.J, Prokushkin A.S 2006 Critical analysis of root : shoot ratios in terrestrial biomes. Global Change Biol. 12, 84–96. doi:10.1111/j.1365-2486.2005.001043.x.

[49] Except for moist evergreen and moist semideciduous NW forest strata where FPP data were available on carbon stocks for grassland and all carbon pools were included (aboveground biomass, belowground biomass, deadwood, litter, non-tree vegetation, soil carbon stocks

[50] Except for the moist semideciduous NW forest strata where FPP data were available on carbon stocks in settlement and all carbon pools were included (aboveground biomass, belowground biomass, deadwood, litter, non-tree vegetation, soil carbon stocks)

<table>
<tr>
<td>description of the assumptions, methods and results of any underlying studies that have been used to determine the parameter:</td>
<td>

Deadwood carbon stocks appeared to be significantly over estimated, however, so IPCC defaults were applied for this pool (aboveground carbon stocks multiplied by 0.06)

Post-deforestation carbon stocks:

Cropland: FPP data on cropland carbon stocks per strata, reflecting all cropland (currently cropped or in fallow), rice fields, and agro-forestry systems
Plantations: Kongsager et al. 2013. Only above and belowground carbon stocks included. Belowground carbon stocks derived by applying Mokany (2006)[51] root-to-shoot ratio of 0.2
Grassland: FPP data where available or IPCC default of 3.1 t C/ha
Wetlands: assumed to be zero
Settlement: FPP data where available assumed to be zero
Bareland/other: assumed to be zero
Water: assumed to be zero

</td>
</tr>
<tr>
<td>Discussion of key uncertainties for this parameter:</td>
<td>Forest carbon stock data are taken from the FPP project that estimated confidence intervals (95% of the mean) for the 6 forest carbon pools for each stratum.

Generally, the FPP plot-based mean values are generated with small number of field plots for each of the ecological zone that leads to relatively high uncertainty. This will be decreased as more data are collected as the programme progresses.</td>
</tr>
<tr>
<td>Estimation of accuracy, precision, and/or confidence level, as applicable and an explanation of assumptions/ methodology in the estimation:</td>
<td>
<table>
<tr><th>Forest carbon Stratum/ Forest type</th><th colspan="2">Post deforestation Stratum</th><th>Uncertainty (%)</th></tr>
<tr><td colspan="4">Wet evergreen</td></tr>
<tr><td>Closed forest</td><td>Cropland</td><td>Cropland (herbaceous and fallow land)</td><td>14.2</td></tr>
</table>
</td>
</tr>
</table>

[51] Mokany K, Raison R.J, Prokushkin A.S 2006 Critical analysis of root : shoot ratios in terrestrial biomes. Global Change Biol. 12, 84–96. doi:10.1111/j.1365-2486.2005.001043.x.

			Plantations	Oil Palm	21.9
				Citrus	27.9
				Rubber	36.6
				Cocoa	11.8
		Grassland			11.0
		Wetlands			21.5
		Settlement			6.9
		Bareland/other			18.1
	Open Forest	Cropland	Cropland (herbaceous and fallow land)		28.6
			Plantations	Oil Palm	57.1
				Citrus	64.1
				Rubber	70.5
				Cocoa	36.7
		Grassland			5.5
		Wetlands			36.6
		Settlement			0.5

		Bareland/other			36.3
	Moist Evergreen				
	Closed forest	Cropland	Cropland (herbaceous and fallow land)		8.6
			Plantations	Oil Palm	16.8
				Citrus	22.7
				Rubber	31.2
				Cocoa	8.0
		Grassland			5.0
		Wetlands			6.3
		Settlement			3.3
		Bareland/other			10.0
	Open Forest	Cropland	Cropland (herbaceous and fallow land)		16.8
			Plantations	Oil Palm	43.6
				Citrus	51.3
				Rubber	59.9

				Cocoa	31.7
		Grassland			26.4
		Wetlands			41.4
		Settlement			13.7
		Bareland/other			33.7
	Moist Semi-deciduous SE				
	Closed forest	Cropland	Cropland (herbaceous and s fallow land)		8.4
			Plantations	Oil Palm	17.3
				Citrus	23.3
				Rubber	32.0
				Cocoa	8.0
		Grassland			5.8
		Wetlands			12.0
		Settlement			4.6
		Bareland/other			9.1
	Open Forest	Cropland	Cropland (herbaceous and fallow land)		20.1

			Plantations	Oil Palm	42.5
				Citrus	50.2
				Rubber	58.9
				Cocoa	17.9
		Grassland			27.1
		Wetlands			36.6
		Settlement			17.1
		Bareland/other			31.0
	Moist Semi-deciduous NW				
	Closed forest	Cropland	Cropland (herbaceous and fallow land)		12.2
			Plantations	Oil Palm	36.6
				Citrus	45.3
				Rubber	55.1
				Cocoa	13.4
		Grassland			5.4

		Wetlands			10.0
		Settlement			2.5
		Bareland/other			15.9
	Open Forest	Cropland	Cropland (herbaceous and fallow land)		17.0
			Plantations	Oil Palm	56.0
				Citrus	63.2
				Rubber	69.9
				Cocoa	24.6
		Grassland			12.0
		Wetlands			19.0
		Settlement			4.4
		Bareland/other			25.3
	Upland Evergreen				
	Closed forest	Cropland	Cropland (herbaceous and fallow land)		20.5
			Plantations	Oil Palm	29.7
				Citrus	35.8

				Rubber	44.5
				Cocoa	16.7
		Grassland			22.8
		Wetlands			26.3
		Settlement			13.7
		Bareland/other			25.1
	Open Forest	Cropland	Cropland (herbaceous and fallow land)		23.2
			Plantations	Oil Palm	45.7
				Citrus	53.9
				Rubber	62.3
				Cocoa	32.5
		Grassland			14.7
		Wetlands			43.0
		Settlement			7.2
		Bareland/other			32.6
	Dry Semi-Deciduous Inner Zone				
	Closed forest	Cropland			21.5

		Grassland	2.5
		Wetlands	2.7
		settlement	1.8
		Bareland/other	24.6
		Water	2.7
	Open Forest	Cropland	20.8
		Grassland	8.4
		Wetlands	9.9
		settlement	6.6
		Bareland/other	25.1
		Water	9.9
	Dry Semi-Deciduous Fire Zone		

	Closed forest	Cropland	20.7
		Grassland	5.2
		Wetlands	2.6
		settlement	1.6
		Bareland/other	26.0
		Water	2.6
	Open Forest	Cropland	19.9
		Grassland	4.4
		Wetlands	0.3
		settlement	0.2
		Bareland/other	24.9
		Water	0.3
	Savannah		

	Closed forest	Cro pla nd	23.3
		Gra ssla nd	6.9
		Wet lan ds	1.0
		sett lem ent	0.6
		Bareland/o ther	28.2
		Wat er	1.0
	Open Forest	Cro pla nd	24.3
		Gra ssla nd	10.1
		Wet lan ds	13.5
		sett lem ent	7.8
		Bareland/o ther	29.5
		Wat er	13.5
	Southern Marginal		

	Closed forest	Cro pla nd	20.4
		Gra ssla nd	15.0
		Wet lan ds	18.4
		sett lem ent	13.5
		Bareland/o ther	23.2
		Wat er	18.4
	Open Forest	Cro pla nd	27.2
		Gra ssla nd	26.9
		Wet lan ds	39.2
		sett lem ent	23.2
		Bareland/o ther	32.3
		Wat er	39.2

	Uncertainties represent 95% confidence intervals as a percentage of the mean

Timber Harvest – Legal

Activity Data

Description of the parameter including the time period covered (e.g. forest-cover change between 2000 – 2005 or transitions between forest categories X and Y between 2003-2006):	Average volume of the logs extracted annually from 2000-2015
Explanation for which sources or sinks the parameter is used (e.g deforestation or forest degradation):	Degradation from legal timber harvest
Data unit (e.g. ha/yr):	m^3/yr
Source of data (e.g. official statistics) or description of the method for developing the data, including (pre-)processing methods for data derived from remote sensing images (including the type of sensors and the details of the images used):	These data present the total volume of logs extracted annually by species and by administrative unit (region and locality) based on the Tree Information Forms (TIFs). This is derived from diameter measurements at both ends of the bole in cm as well as the length of the bole in meters. The parameters measured are then used to estimate the volume using Smalian's formula
Discussion of key uncertainties for this parameter:	This is a forest concession census of actual timber volume extracted, so very small uncertainty is assumed—most likely as measurement error of the logs (diameters, lengths and number of logs). Standard

	operating procedure used for these measurements should minimize this, however.
Estimation of accuracy, precision, and/or confidence level, as applicable and an explanation of assumptions/methodology in the estimation:	This is a forest concession census of actual timber volume, so very small uncertainty is assumed—most likely as measurement error of the logs (diameters, lengths and number of logs). Standard operating procedure used for these measurements should minimize this, however.

Emission Factors

Description of the parameter including the forest class if applicable:	The emission factor for selective logging activity in Ghana, including emissions from extracted logs, logging infrastructure, and logging damage.
Data unit (e.g. t CO_2/ha):	t CO_2/m^3
Source of data (e.g. official statistics, IPCC, scientific literature) or description of the assumptions, methods and results of any underlying studies that have been used to determine the parameter:	Field data collection by the Forestry Commission is the main source of data. Additional assumptions and data sources are explain in more details in see Annex B.
Discussion of key uncertainties for this parameter:	The standard operating procedures (Annex D) followed minimizes the uncertainty associated with data collection. Other sources of uncertainty include: - The average milling efficiency associated with legal timber harvest is based on a literature view and reported averages from the Forestry Commission. - Estimation of the weighted average of wood density based on Ghana Forestry Commission estimates per species logged. - A half-life of and a decay rate are applied as given in Table 12.2 in IPCC 2006[52].

[52] Footnote 53

	- carbon stock derived from the FPP inventory dataset. - no volumes could be paired with emission per length of road. This correlation instead had to rely on the study of Medjibe et al (2013) from Gabon.[53] - For logging decks volume correlations were similarly unavailable. This correlation instead had to rely on the study of Medjibe et al (2013) from Gabon.[54] This paired with FPP inventory data produced a decks emission factor.
Estimation of accuracy, precision, and/or confidence level, as applicable and an explanation of assumptions/methodology in the estimation:	The emissions factors are developed based on 243 logging gaps measured by the Forestry Commission. The extracted log emission (ELE) had an uncertainty equal to 2.5% of the mean at the 95% confidence level. The logging damage factor (LDF) had an uncertainty equal to 6.9% of the mean at the 95% confidence level. The logging impact factor (LIF) had an uncertainty equal to 26% of the mean at the 95% confidence level. Using a weighted propagation of errors approach the total emission factor (TEF) had an uncertainty equal to 5.7% of the mean at the 95% confidence level.

Timber Harvest – Illegal

Activity Data

Description of the parameter including the time period covered (e.g. forest-cover change between 2000 – 2005 or transitions between forest categories X and Y between 2003-2006):	The activity data for illegal timber harvest at this stage will consist of the peer-reviewed literature estimate of Hansen et al. (2012). Hansen estimated illegal logged timber at 4.1 million m^3 per year in 2009.

[53] Medjibe, V.P., Putz, F.E., Romero, C. (2013) Certified and uncertified logging concessions compared in Gabon: Changes in stand structure, tree species, and biomass. Environmental Management. DOI 10.1007/s00267-012-0006-4

[54] Medjibe, V.P., Putz, F.E., Romero, C. (2013) Certified and uncertified logging concessions compared in Gabon: Changes in stand structure, tree species, and biomass. Environmental Management. DOI 10.1007/s00267-012-0006-4

Explanation for which sources or sinks the parameter is used (e.g deforestation or forest degradation):	Degradation from illegal timber harvest
Data unit (e.g. ha/yr):	m^3/yr
Source of data (e.g. official statistics) or description of the method for developing the data, including (pre-)processing methods for data derived from remote sensing images (including the type of sensors and the details of the images used):	HANSEN, C.P., L. DAMNYAG, B.D. OBIRI and K. CARLSEN 2012. Revisiting illegal logging and the size of the domestic timber market: the case of Ghana *International Forestry Review Vol.**14**(1), 2012* 39 It can be reasonably assumed that the reported number reflects the estimated annual volume of illegally extracted timber in GCFRP accounting area because the paper states "the timber resources are located in the High Forest Zone". It can also be expected that this number is an underestimate as illegal logging is believed to have increased in recent years. This will be conservative as actual illegal volumes are monitored under MRV
Discussion of key uncertainties for this parameter:	Uncertainty is unknown so at this stage prior to an illegal logging monitoring system in Ghana. Given the numbers here result from a single study in a single year, to be highly conservative an uncertainty value is used that is equal to half the value of the parameter.
Estimation of accuracy, precision, and/or confidence level, as applicable and an explanation of assumptions/methodology in the estimation:	50% uncertainty is assumed. 4.1 million m^3/yr ± 2.05 million m^3/yr

Emission Factors

Description of the parameter including the forest class if applicable:	The emission factor for illegal logging activity in Ghana, accounting for emissions from extracted logs and logging damage.
Data unit (e.g. t CO_2/ha):	t CO_2/m^3

Source of data (e.g. official statistics, IPCC, scientific literature) or description of the assumptions, methods and results of any underlying studies that have been used to determine the parameter:	Field data collection by the Forestry Commission is the main source of data. Additional assumptions and data sources are explained in further detail in Annex 7.
Discussion of key uncertainties for this parameter:	Following the standard operating procedures (Annex 9) minimizes the uncertainty associated with data collection. Other sources of uncertainty include: - The average milling efficiency associated with legal timber harvest is based on literature review. - Estimation of the weighted average of wood density based on Ghana Forestry Commission estimates per species logged. - A half-life of and a decay rate are applied as given in Table 12.2 in IPCC 2006[55]. - Carbon stock derived from the FPP inventory dataset.
Estimation of accuracy, precision, and/or confidence level, as applicable and an explanation of assumptions/methodology in the estimation:	The emissions factors are developed based on 243 logging gaps measured by the Ghana Forestry Commission. The extracted log emission (ELE) had an uncertainty equal to 3.7% of the mean at the 95% confidence level. The logging damage factor (LDF) had an uncertainty equal to 6.9% of the mean at the 95% confidence level. Using a weighted propagation of errors approach the total emission factor (TEF) had an uncertainty equal to 5.3% of the mean at the 95% confidence level.

[55] IPCC (2006) Guidelines for national greenhouse gas inventories. Volume 4: Agriculture, Forestry, and Other Land Use. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Forest Fire

Activity data

Description of the parameter including the time period covered (e.g. forest-cover change between 2000 – 2005 or transitions between forest categories X and Y between 2003-2006):	Burned area for forest remaining forest between 2000-2015.
Explanation for which sources or sinks the parameter is used (e.g deforestation or forest degradation):	Forest degradation
Data unit (e.g. ha/yr):	Ha
Source of data (e.g. official statistics) or description of the method for developing the data, including (pre-)processing methods for data derived from remote sensing images (including the type of sensors and the details of the images used):	MODIS burned area product
Discussion of key uncertainties for this parameter:	Given large pixel size ($500m^2$), the MODIS product is unlikely to capture small degradation fires. Surface fires are also unlikely to be captured as mortality of canopy vegetation is limited and cannot be detected by satellite images. Other potential remote sensing errors include: haze from smoke, cloud cover and coastal moisture effects.

Estimation of accuracy, precision, and/or confidence level, as applicable and an explanation of assumptions/methodology in the estimation:	According to Roy and Boschetti (2009)[56], average MODIS burned area agreement with Landsat-measured burned area is 96%.

Emission Factors

Description of the parameter including the forest class if applicable:	Biomass available for combustion
Data unit (e.g. t CO_2/ha):	t C/ha
Source of data (e.g. official statistics, IPCC, scientific literature) or description of the assumptions, methods and results of any underlying studies that have been used to determine the parameter:	Forest Preservation Programme (FPP) forest carbon stock inventory collected through Mapping of Forest Cover and Carbon Stock in Ghana project.
Discussion of key uncertainties for this parameter:	Forest carbon stock data are taken from the FPP project that estimated confidence intervals (95% of the mean) for the 6 forest carbon pools for each stratum. Generally, the FPP plot-based mean values are generated with small number of field plots for each of the ecological zone that leads to relatively high uncertainty. This will be decreased as more data are collected as the programme progresses
Estimation of accuracy, precision, and/or confidence level, as applicable and an	<table><tr><th>Forest carbon</th><th>Uncertainty %</th></tr></table>

[56] Roy DP and Boschetti L (2009) Southern Africa validation of the MODIS, L3RC, and GlobCarbon burned area products. *IEEE Transactions on Geoscience and Remote Sensing*: 47(4).

explanation of assumptions/methodology in the estimation:	Stratum/ Forest type	
	Wet evergreen	
	Closed Forest	11.4
	Open Forest	1.8
	Moist Evergreen	
	Closed Forest	5.0
	Open Forest	27.2
	Moist Semi-deciduous SE	
	Closed Forest	5.8
	Open Forest	29.0
	Moist Semi-deciduous NW	
	Closed Forest	4.3
	Open Forest	11.4
	Upland Evergreen	
	Closed Forest	23.9
	Open Forest	15.3
	Dry Semi-Deciduous Inner Zone	
	Closed Forest	2.7
	Open Forest	9.9

	Dry Semi-Deciduous Fire Zone	
	Closed Forest	2.6
	Open Forest	0.3
	Savannah	
	Closed Forest	1.0
	Open Forest	13.5
	Southern Marginal	
	Closed Forest	18.4
	Open Forest	39.2
	Uncertainties represent 95% confidence intervals as a percentage of the mean	

Description of the parameter including the time period covered (e.g. forest-cover change between 2000 – 2005 or transitions between forest categories X and Y between 2003-2006):	Emission factor
Explanation for which sources or sinks the parameter is used (e.g deforestation or forest degradation):	Forest degradation
Data unit (e.g. ha/yr):	G kg^{-1} dry matter burnt
Source of data (e.g. official statistics) or description of the method for developing the data, including (pre-)processing methods	IPCC (2006) Table 2.5

for data derived from remote sensing images (including the type of sensors and the details of the images used):	
Discussion of key uncertainties for this parameter:	Taken from IPCC (2006)
Estimation of accuracy, precision, and/or confidence level, as applicable and an explanation of assumptions/methodology in the estimation:	Uncertainty as given by IPCC (2006) are as follows as a percentage of the value: CO_2: 6% CH_4: 29% N_2O: 100%

Woodfuel

Description of the parameter including the time period covered (e.g. forest-cover change between 2000 – 2005 or transitions between forest categories X and Y between 2003-2006):	Woodfuel emissions 2000-2015
Explanation for which sources or sinks the parameter is used (e.g deforestation or forest degradation):	Forest degradation
Data unit (e.g. ha/yr):	t CO_2/yr
Source of data (e.g. official statistics) or description of the method for developing the data, including (pre-)processing methods	WISDOM Model Inputs: **Supply - Biomass + Productivity:** • Biomass Stocks (woody AGB without twigs and stumps) • Geo-referenced plot data from field surveys

for data derived from remote sensing images (including the type of sensors and the details of the images used):	• Forest inventories of specific locations forest/vegetation types • Empirically-derived maps of biomass distribution (Saatchi et al. 2011; Baccini et al. 2012) • Productivity: Stock and Mean Annual Increment (IPCC) **Demand:** • GLOBAL Gridded Population Maps and Data • Global Administrative Unit Layers • International databases of forestry/energy statistics ○ FAOSTAT ○ International Energy Agency ○ United Nations Energy ○ National-level data sources ○ World Health Organization databases on house hold fuel choice
Discussion of key uncertainties for this parameter:	The model combines a wide array of datasets and approaches and thus there is no single associated uncertainty estimate. As the numbers used result from a single year in the reference period, to be highly conservative prior to systematic collection of woodfuel data in Ghana, an uncertainty equal to 50% of the parameter value is assumed.
Estimation of accuracy, precision, and/or confidence level, as applicable and an explanation of assumptions/methodology in the estimation:	Uncertainty as a percentage of the parameter value: 50%

Enhancement

Activity Data

Description of the parameter including the time period covered (e.g. forest-cover change between 2000 – 2005 or transitions between forest	Average annual area of forests planted into the forest reserves between 2000-2015, discounted by plantation failure rates.

categories X and Y between 2003-2006):	
Explanation for which sources or sinks the parameter is used (e.g deforestation or forest degradation):	Carbon stock enhancements
Data unit (e.g. ha/yr):	Hectares planted/yr
Source of data (e.g. official statistics) or description of the method for developing the data, including (pre-)processing methods for data derived from remote sensing images (including the type of sensors and the details of the images used):	National Forest Plantation Development Programme official statistics. The NFPDP collects data on for on-reserve tree establishment across Ghana, and include a number of programmes that took place along different timeframes between 2002-2015: Government Plantation Development Programme (GPDP), Modified Taungya System (MTS), Community Forestry Management Project (CFMP), Model plantations, and other on-reserve planting programmes (detailed in Annex B). While spatial data were not available on area planted, historical tabular data are organized into hectares planted per forest reserve. For the development of historical removals within the GCFRP Accounting Area, it was necessary to isolate how many hectares were planted in forest reserves located within the ER-Programme area (GCFRP Accounting Area). Shapefiles of forest reserve boundaries were used to delineate which forest reserves were located within GCFRP Accounting Area boundaries, and only those inside the GCFRP Accounting Area were included. For plantings in forest reserves that fell both within and outside the GCFRP Accounting Area boundary, the proportion of the forest reserve inside and outside the boundary was calculated, and the only proportion of planted area within GCFRP Accounting Area boundary was applied. To account for plantation failure, the recorded annual area planted within the GCFRP Accounting Area was discounted based on official statistics from the NFPDP. These official statistics reflect the two distinct periods of activities that the NFPDP undertook, whereby the 2001-2009 period reflected plantation activities in forest reserves

	largely led by the public sector. Starting in 2010, activities shifted toward issuing private sector companies leases to establish plantations within forest reserves. This shift in activities and management appears to have resulted in significantly different plantation failure rates: • 2001-2009: "Survey and Mapping of Government Plantation Sites Established between 2004 and 2009 in some Forest Reserves of Ghana" stated that 44.9% of the planted area was estimated to have failed during this time period. • 2010-2015: The NFPDP 2013 Dataset on Final Verification Nationwide included estimates of survival percentage per forest reserve. The average survival percentage for 2013 was reported as 75.43%, and thus a failure rate of 24.6% was applied. For the year 2013, actual survival rates per forest reserve were used rather than the average. The adjusted annual estimates for area planted were then divided according to species composition, so that appropriate removal factors could be applied. The total estimated area of successful plantations was assumed to be comprised of 70% teak species and 30% other broadleaf species. This assumption about species composition was made based on expert opinion as well as a review of NFPDP data.
Discussion of key uncertainties for this parameter:	The activity data used for the estimation of removals was derived from national census data, reported by the National Forest Plantation Development Programme. As such, no uncertainty is assumed.
Estimation of accuracy, precision, and/or confidence level, as applicable and an explanation of assumptions/methodology in the estimation:	Effectively zero uncertainty is assumed for this parameter.

Removal Factors

Description of the parameter including the forest class if applicable:	Calculated removal factor for carbon stock enhancement through plantation of teak in forest reserves (AGB and BGB)
Data unit (e.g. t CO_2/ha):	t CO_2 /ha
Source of data (e.g. official statistics, IPCC, scientific literature) or description of the assumptions, methods and results of any underlying studies that have been used to determine the parameter:	Published literature (Adu-Bredu S., et al. 2008[57]) on total tree carbon stocks in teak stands in moist evergreen forest in Ghana (98 Mg C/ ha) and in the savannah zone (26 Mg C/ha) (included both aboveground and belowground carbon stocks). Moist Evergreen Forest teak long-term carbon stocks: 98 / 2 = 49 = 179 t CO_2/ha Savannah teak long-term carbon stocks: 26 / 2 = 13 = 47.8 t CO_2/ha
Discussion of key uncertainties for this parameter:	Adu-Bredu et al. (2008) was completed using temporary sample plots following standard operating procedures for the measurement of terrestrial carbon.
Estimation of accuracy, precision, and/or confidence level, as applicable and an explanation of assumptions/methodology in the estimation:	While only the total tree carbon stocks were used for the development of removal factors, an estimation of statistical accuracy was offered in the form of the mean, minimum, and maximum carbon values for the total carbon stocks of the teak stands studied in the moist evergreen forest strata, as well as the standard deviation: Mean: 138 Minimum: 133 Maximum: 144 Based on these values a conservative value for uncertainty is 6% of the mean.

[57] Adu-Bredu S., et al. (2008). Carbon Stock under Four Land-Use Systems in Three Varied Ecological Zones in Ghana. Proceedings of the Open Science Conference on Africa and Carbon Cycle: the CarboAfrica project, Accra, Ghana, 25-27 November 2008. Available at http://www.fao.org/3/a-I2240.pdf

Description of the parameter including the forest class if applicable:	Calculated removal factor for carbon stock enhancement through plantation of trees (non-teak) in forest reserves (AGB and BGB)
Data unit (e.g. t CO_2/ha):	t CO_2 /ha
Source of data (e.g. official statistics, IPCC, scientific literature) or description of the assumptions, methods and results of any underlying studies that have been used to determine the parameter:	IPCC AFOLU Vol. 4 table 4.8 above-ground biomass in forest plantations. Values for 'Africa broadleaf >20 years' for three ecological zones in the GCFRP Accounting Area (tropical rain forest, tropical moist deciduous forest, and tropical dry forest) were averaged, and converted to carbon (86.65 t C/ha). The belowground biomass value was generated by applying a root-to-shoot ratio of 0.235 for tropical/subtropical moist forest/plantations >125 Mg ha-1 (Mokany et al.2006)[58]. This rendered a total stock of 107 t C/ha. Long-term carbon stocks: 107/2 = 53.5 t C/ha =196 t CO_2/ha.
Discussion of key uncertainties for this parameter:	For the development of this parameter, IPCC defaults for aboveground biomass in forest plantations in Africa were applied. Given they are continental averages for all broadleaf species, uncertainty can be assumed to be high. As belowground biomass stocks are produced using a root-to-shoot ratio (Mokany et al., 2006)[59], and therefore values are tied to the estimates for aboveground biomass.
Estimation of accuracy, precision, and/or confidence level, as applicable and an explanation of assumptions/methodology in the estimation:	No uncertainty values were offered in the IPCC tables (both IPCC 2003 and 2006) for this parameter, while there is uncertainty in the specific number for removal stock the scale of the variation is constrained biologically. Thus here, a 33% is adopted.

[58] Mokany K, Raison R.J, Prokushkin A.S 2006 Critical analysis of root : shoot ratios in terrestrial biomes. Global Change Biol. 12, 84–96. doi:10.1111/j.1365-2486.2005.001043.x.
[59] Mokany K, Raison R.J, Prokushkin A.S 2006 Critical analysis of root : shoot ratios in terrestrial biomes. Global Change Biol. 12, 84–96. doi:10.1111/j.1365-2486.2005.001043.x.

Summed Uncertainties

Activity	Sources of Uncertainty	Summed Uncertainty				
		Forest carbon Stratum/ Forest type	Post deforestation Stratum			Uncertainty (%)
		Wet evergreen				
Deforestation	Uncertainty in remote sensing of land cover maps as identified in the confusion matrices Sampling uncertainty for the measurement data for emission factors[60]	Closed forest	Cropland	Cropland (herbaceous and fallow land)		21.4
				Plantations	Oil Palm	27.1
					Citrus	32.1
					Rubber	40.0
					Cocoa	19.9
			Grassland			19.4
			Wetlands			26.8
			Settlement			17.4
			Bareland/other			24.1

[60] Spreadsheets show calculation of uncertainty across pools for the emission factors. Combination with activity data relies of the 84% accuracy of classification (thus 16% uncertainty)

		Open Forest	Cropland	Cropland (herbaceous and fallow land)		32.8
				Plantations	Oil Palm	59.3
					Citrus	66.0
					Rubber	72.3
					Cocoa	40.0
			Grassland			16.9
			Wetlands			39.9
			Settlement			16.0
			Bareland/other			39.7
		Moist Evergreen				
		Closed forest	Cropland	Cropland (herbaceous and fallow land)		18.2
				Plantations	Oil Palm	23.2
					Citrus	27.8
					Rubber	35.1
					Cocoa	17.9
			Grassland			16.8

			Wetlands			17.2
			Settlement			16.3
			Bareland/other			18.9
		Open Forest	Cropland	Cropland (herbaceous and fallow land)		23.2
				Plantations	Oil Palm	46.4
					Citrus	53.8
					Rubber	62.0
					Cocoa	35.5
			Grassland			30.9
			Wetlands			44.3
			Settlement			21.1
			Bareland/other			37.3
		Moist Semi-deciduous SE				
		Closed forest	Cropland	Cropland (herbaceous and fallow land)		18.1
				Plantations	Oil Palm	23.6
					Citrus	28.3

					Rub ber	35.8
					Coc oa	17.9
			Grassland			17.0
			Wetlands			20.0
			Settlement			16.6
			Bareland/other			18.4
		Open Forest	Cropland	Cropland (herbaceous and fallow land)		25.7
				Plantati ons	Oil Pal m	45.4
					Citr us	52.7
					Rub ber	61.0
					Coc oa	24.0
			Grassland			31.4
			Wetlands			39.9
			Settlement			23.4
			Bareland/other			34.9
		Moist Semi-deciduous NW				
		Closed forest	Cropland	Cropland (herbaceous and fallow land		20.1

				Plantations	Oil Palm	40.0
					Citrus	48.1
					Rubber	57.3
					Cocoa	20.9
			Grassland			16.9
			Wetlands			18.9
			Settlement			16.2
			Bareland/other			22.6
		Open Forest	Cropland	Cropland (herbaceous and fallow land)		23.4
				Plantations	Oil Palm	58.2
					Citrus	65.2
					Rubber	71.7
					Cocoa	29.4
			Grassland			20.0
			Wetlands			24.8
			Settlement			16.6
			Bareland/other			30.0

		Upland Evergreen				
		Closed forest	Cropland	Cropland (herbaceous and fallow land		26.0
				Plantati ons	Oil Pal m	33.7
					Citr us	39.2
					Rub ber	47.3
					Coc oa	23.1
			Grassland			27.8
			Wetlands			30.7
			Settlement			21.1
			Bareland/other			29.7
		Open Forest	Cropland	Cropland (herbaceous and fallow land)		28.2
				Plantati ons	Oil Pal m	48.5
					Citr us	56.2
					Rub ber	64.4
					Coc oa	36.2
			Grassland			21.7

			Wetlands	45.9
			Settlement	17.6
			Bareland/other	36.3
		Dry Semi-Deciduous Inner Zone		
		Closed forest	Cropland	26.8
			Grassland	16.2
			Wetlands	16.2
			settlement	16.1
			Bareland/other	29.4
			Water	16.2
		Open Forest	Cropland	26.2
			Grassland	18.1
			Wetlands	18.8
			settlement	17.3
			Bareland/other	29.7
			Water	18.8
		Dry Semi-Deciduous Fire Zone		

		Closed forest	Cropland	26.1
			Grassland	16.8
			Wetlands	16.2
			settlement	16.1
			Bareland/other	30.6
			Water	16.2
		Open Forest	Cropland	25.6
			Grassland	16.6
			Wetlands	16.0
			settlement	16.0
			Bareland/other	29.6
			Water	16.0
		Savannah		
		Closed forest	Cropland	28.3
			Grassland	17.4

			Wetlands	16.0
			settlement	16.0
			Bareland/other	32.4
			Water	16.0
		Open Forest	Cropland	29.1
			Grassland	18.9
			Wetlands	20.9
			settlement	17.8
			Bareland/other	33.6
			Water	20.9
		Southern Marginal		
		Closed forest	Cropland	25.9
			Grassland	22.0
			Wetlands	24.4
			settlement	20.9
			Bareland/other	28.2
			Water	24.4

		Open Forest	Cropland	31.5
			Grassland	31.3
			Wetlands	42.4
			settlement	28.2
			Bareland/other	36.0
			Water	42.4
Legal Timber Harvest	Sampling uncertainty for emission factors	5.7%		
Illegal Timber Harvest	Sampling uncertainty for estimates of illegal logging volumes. Sampling uncertainty for emission factors	53%		
Woodfuel	Sampling uncertainty for woodfue	50%		

<table>
<tr><td></td><td>l supply volumes.

Model uncertainty for woodfuel demand volumes</td><td></td></tr>
<tr><td>Fire</td><td>Uncertainty resulting from the coarseness of MODIS data

Uncertainty from the IPCC default factors

Sampling uncertainty for emission factors</td><td>
<table>
<tr><th>Forest carbon Stratum/ Forest type</th><th>Uncertainty

%</th></tr>
<tr><td colspan="2">Wet evergreen</td></tr>
<tr><td>Closed Forest</td><td></td></tr>
<tr><td>CO_2</td><td>38.4</td></tr>
<tr><td>CH_4</td><td>48.0</td></tr>
<tr><td>N_2O</td><td>107.0</td></tr>
<tr><td>Open Forest</td><td></td></tr>
<tr><td>CO_2</td><td>36.7</td></tr>
<tr><td>CH_4</td><td>46.7</td></tr>
<tr><td>N_2O</td><td>106.4</td></tr>
<tr><td colspan="2">Moist Evergreen</td></tr>
<tr><td>Closed Forest</td><td></td></tr>
<tr><td>CO_2</td><td>37.0</td></tr>
<tr><td>CH_4</td><td>46.9</td></tr>
</table>
</td></tr>
</table>

		N_2O	106.5	
		Open Forest		
		CO_2	45.6	
		CH_4	54.0	
		N_2O	109.8	
		Moist Semi-deciduous SE		
		Closed Forest		
		CO_2	37.1	
		CH_4	47.0	
		N_2O	106.5	
		Open Forest		
		CO_2	46.7	
		CH_4	54.9	
		N_2O	110.2	
		Moist Semi-deciduous NW		
		Closed Forest		
		CO_2	36.9	
		CH_4	46.8	
		N_2O	106.4	
		Open Forest		
		CO_2	38.4	
		CH_4	48.0	
		N_2O	107.0	

		Upland Evergreen		
		Closed Forest		
		CO_2	43.8	
		CH_4	52.4	
		N_2O	109.0	
		Open Forest		
		CO_2	39.7	
		CH_4	49.1	
		N_2O	107.4	
		Dry Semi-Deciduous Inner Zone		
		Closed Forest		
		CO_2	36.8	
		CH_4	46.7	
		N_2O	106.4	
		Open Forest		
		CO_2	38.0	
		CH_4	47.7	
		N_2O	106.8	
		Dry Semi-Deciduous Fire Zone		
		Closed Forest		
		CO_2	36.8	
		CH_4	46.7	
		N_2O	106.4	

		Open Forest		
		CO_2	36.7	
		CH_4	46.7	
		N_2O	106.4	
		Savannah		
		Closed Forest		
		CO_2	36.7	
		CH_4	46.7	
		N_2O	106.4	
		Open Forest		
		CO_2	39.1	
		CH_4	48.6	
		N_2O	107.2	
		Southern Marginal		
		Closed Forest		
		CO_2	41.0	
		CH_4	50.1	
		N_2O	107.9	
		Open Forest		
		CO_2	53.7	
		CH_4	60.9	
		N_2O	113.4	

Enhancement	Sampling uncertainty for removal factors	Teak: 6% Other: 33%

ANNEX B. MAPPING UNSHADED COCOA AND MONOCULTURE PLANTATIONS IN THE HIGH FOREST ZONE OF GHANA

Background and Introduction

Ghana has been mapping land cover change with a focus on the broad conversion of forest to non-forest.

The goal of the work conducted by AGS was to evaluate the feasibility of and create a system for mapping cocoa and large monoculture plantations like oil palm, rubber, and citrus as separate from their current inclusion as either forest or non-forest. Additionally, the AGS team was to lead a capacity building workshop in Ghana outlining results and sharing the methods employed in this mapping exercise.

The primary objective of the project was to evaluate the feasibility of separating cocoa and monoculture plantations from forest, as measured by level of effort required and accuracy of resulting product. To meet this objective, the AGS team developed a method for detailed classification and created initial maps for a reference period (2000 and 2013), and for 2015 for MRV. The improved mapped areas of cocoa and monoculture plantations will be used to exclude cocoa and monoculture plantation areas from further tracking because they don't meet the definition of forest, thereby improving the forest/non-forest maps.

Forests are defined as one hectare contiguous areas with at least 15% canopy cover from trees 5 meters or taller. The only exception to this is monoculture plantations, which, while meeting this definition, are not considered forest. Cocoa farms with canopy coverage of more than 15% from shade trees are considered forest under this definition.

Methods

Mapping detailed land cover classes such as unshaded cocoa and monoculture plantations requires higher quality imagery (i.e. imagery with limited atmospheric variability) because the differences between the spectral and textural signature of the target classes to be mapped can be subtle. We acquired Landsat data from the USGS (http://earthexplorer.usgs.gov/), with a focus on scenes with limited clouds and atmospheric contamination (i.e. haze). Our focus here was on the southern central portion of Ghana in the High Forest Zone, tiles 194055 and 194056. Given our criteria for the highest quality imagery, we selected images from the dates 7 May 2002 (2002127), 23 December 2013 (2013357), and 21 December 2015 (2015355).

The Landsat imagery from the USGS are provided as digital numbers (DN). We converted these simplified measurements of radiance to surface reflectance using our open source Geospatial Image Processing System (GIPS). This system is freely available at http://gipit.github.io/gips/. Within this system, atmospheric correction is performed with the 6S model (Vermote et al. 1997). Clouds and thick haze are masked with a modified version of the ACCA algorithm (Irish et al. 2006). Additionally, the image acquired in 2015 has missing data due to the Scanline Corrector Failure on Landsat 7 (Williams et al. 2006). No sufficiently cloud- and haze-free data were available in 1999, 2000, or 2001 for either Landsat 5 or 7 nor in 2015/early 2016 from Landsat 8.

Via the GIPS software, we generated several vegetation indices. Vegetation indices are intended to isolate attributes of the land surface and reduce residual atmospheric and sun-sensor geometry effects. Here, we used the indices listed in Table 1B. These indices were stacked the two tiles (194055 and 194056) were merged into a single raster. This raster was used as input into our classification system.

Table 1B. Landsat and PALSAR indices

NDVI	(NIR – Red) / (NIR + Red)
LSWI	(NIR – SWIR1) / (NIR + SWIR1)
SATVI	(SWIR1 – Red / (SWIR1 + Red + L)) * (1+L) - (SWIR2/2)
NDTI	(SWIR 1 – SWIR 2) / (SWIR 1 + SWIR 2)
Brightness	0.3561(Blue) + 0.3972(Green) + 0.3904(Red) + 0.6966(NIR) + 0.2286(SWIR 1) + 0.1596(SWIR2)
Greenness	-0.3344(Blue) - 0.3544(Green) + -0.4556(Red) + 0.6966(NIR) - 0.0242(SWIR 1) - 0.2630(SWIR2)

Wetness	0.2626(Blue) + 0.2141(Green) + 0.0926(Red) + 0.0656(NIR) - 0.7629(SWIR 1) - 0.5388(SWIR2)
MSI	SWIR 1 / NIR
RFDI	(HH – HV) / (HH + HV)

For the generation of the 2015 maps, we also used SAR backscatter from PALSAR2, available as mosaics from the Japanese Space Agency (JAXA; http://www.eorc.jaxa.jp/ALOS/en/palsar_fnf/data/index.htm), in addition to the Landsat. We converted the digital numbers provided in the mosaics to sigma nought backscatter. In addition to the HH and HV polarizations, we generated two indices HH/HV^2 and RFDI ((HH – HV)/(HH + HV)). These observations are originally provided in geographic coordinates at the 0.000222 degrees spatial resolution. We reprojected and resampled the data using nearest neighbor to match the Landsat 30 m grid (UTM zone 30 WGS84 datum).

The classification approach applied here is supervised, meaning training or calibration data were required. We collected calibration data from two primary sources. The team collected 97 observations, primarily of cocoa, in April 2016. These observations included digitized field boundaries of the observed areas. For the cocoa class, we used only those with less than 15% shade or tree canopy cover. Additionally, we digitized polygons for cocoa, oil palm plantations, natural forest, citrus plantations, rubber plantations, settlement, water, grassland, and crop land (Figure 1B). The boundaries for these areas were digitized using high resolution imagery from 2015, as well as 1997-2003 for the 2002 map and 2012-2013 for the 2013 map. Indications of land use type were guided by NCRC field sampling points (for citrus and rubber) and Oil Palm Grower Association shapefiles (for oil palm). In total, we used 554 polygons for calibration and validation of the 2015 map, 484 polygons for the 2013 map, and 268 polygons for the 2002 map

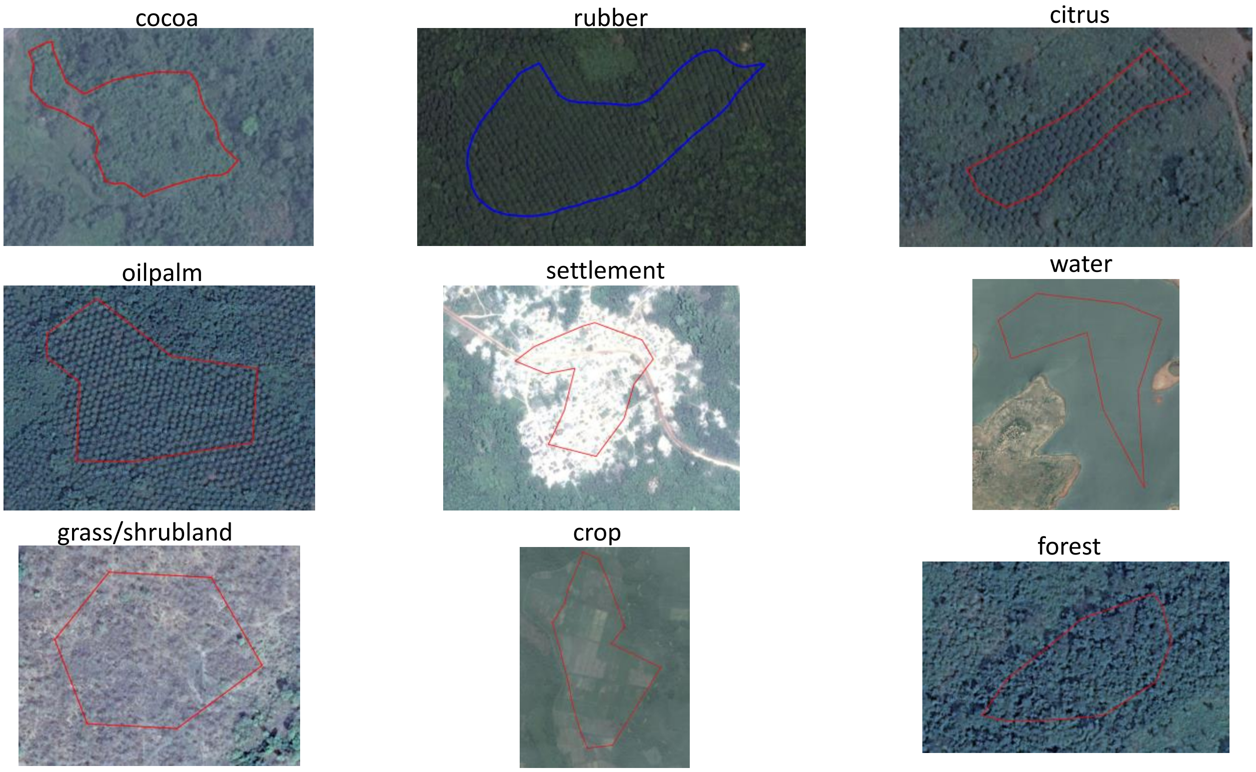

Figure 1B: Example of calibration and validation polygons digitized using Google Earth Pro

For supervised classification, we used our **G**eneral **A**utomated **R**emote **Se**nsing **C**lassification Tool (GARSeCT) to create maps. GARSeCT is a Random Forest classifier (SciKits-Learn python module) wrapped in python code to facilitate the efficient application of remote sensing classification. A Random Forest classifier falls under the general category of "Machine Learning" methods. It is an "Ensemble Learning" algorithm, meaning that several models are combined to solve a single prediction problem. In this case, each component model application is a Classification Decision Tree. A Decision Tree asks a series of binary questions which maximize the information we get about the response variable (class). It performs a "greedy search", asking which one binary question will maximize the info about Y (the class)? Each root node produces two daughter nodes. At each daughter node, we repeat recursively. The advantages of using a decision tree classifier include ease of use, sensitivity to linear and non-linear relationships, provision of information on feature importance, and general avoidance of overfitting.

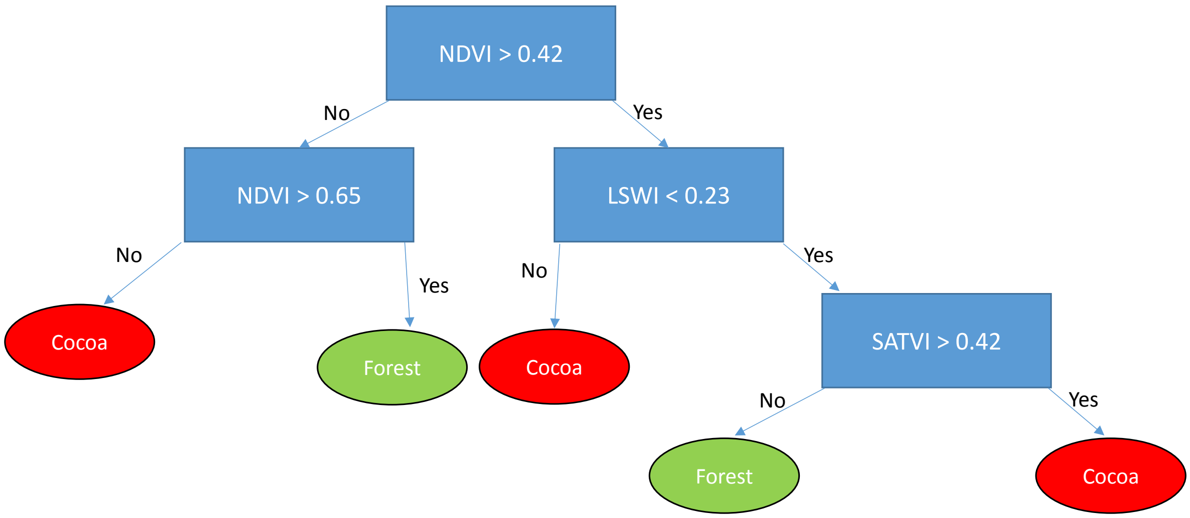

Figure 2B: Example classification tree (for illustration only).

The stacks of processed raster data and digitized training data are provided as input to GARSeCT. We performed separate classifications for 2002, 2013, and 2015. GARSeCT returns a classified map, cross-validation results, and maps of likelihood of class membership. We ran GARSeCT using 100 trees. Each tree relies on a different subset of data for training, and therefore, can produce different classifications for each pixel, thereby "casting a vote" for class membership for each pixel. These "votes" are tallied and captured in the likelihood of class membership maps, and the class with the most votes for each pixel is reported in the classification map.

We visually inspected the resultant maps. There was some general concern that our approach was over predicting cocoa at the expense of forest. Any 1 ha area with tree canopy cover of more than 15% from trees over 5 m is considered forest. We adjusted our classification maps using the class likelihood maps. We set a forest threshold of 10% in 2002, 5% in 2013, and 20% in 2015, meaning any pixel with a forest class likelihood over this threshold is re-classified as forest. Additionally, we performed manual clean-up by digitizing areas of known error and correcting the classification.

Uncertainty in mapped area estimates of class were assessed using the methods outlined in Olofsson et. al. 2014.

Results

Consistently, we found that tasseled cap (TC) wetness, SATVI, TC-brightness, and NDVI provided the most predictive power. In the 2015 classification, the four metrics derived from PALSAR provided the least predictive power. Our results showed significant confusion between some classes, particularly the plantation classes. Specifically, oil palm (59%) and rubber (60%) showed low reliability or user's accuracy. We post-processed the classification maps to simplify the classifications to four classes: *cocoa*, *plantation* (from oil palm, rubber, and citrus), *forest*, and *other* (from settlement, water, grass, and crops). For 2015, out of sample user's accuracy was 77% for cocoa, 81% for plantation, 96% for forest, and 97% for other. For 2002 and 2013, out of sample accuracy was generally lower: 50% and 80% for *cocoa*, 63% and 80% for *plantation*, 69% and 78% for *forest*, and 85% and 89% for *other*.

The Project Area (i.e. high forest zone) of Ghana covers more than 7.5 million ha. The two Landsat path/rows selected for this demonstration analysis cover approximately 5.5 million ha (72%) of the Project Area. In reality, due to the heavy data loss from clouds, haze, and SLC off, true coverage of the Project Area in this analysis totals 1.4 million ha (18%) in 2002, 2.0 million ha (26%) in 2013, and 3.0 million ha (40%) in 2015. The land cover change transition pairs require a clear observation at both time one and time two, reducing the area covered again. The 2002 to 2013 transition period covered only 700,000 ha, while the 2002 to 2015 transition period covered approximately 1.0 million ha. Mapped area fraction within each class changes from year to year based on a) land use change and b) the changing area of analysis due to changing available data.

We estimated uncertainty in the mapped area fraction of each class in each year's map using the approach outlined in Olofsson et al. 2014. The percent areas are presented with 90% confidence limits. We did not estimate the uncertainty in land cover change directly because reference data identifying the change or static nature of reference areas were not collected as part of this project. We only have reference data for the land cover state, not change.

Table 2B. Area fraction in each general class in each of the three mapped years, with 90% confidence limits.

		2002			2013			2015	
	low	mapped	high	low	mapped	High	low	mapped	high
Cocoa	0.0%	1.8%	5.7%	5.2%	6.7%	8.3%	14.7%	15.4%	16.1%
Plantation	5.8%	11.3%	16.7%	0.0%	3.2%	6.6%	3.1%	4.0%	4.8%
Forest	53.0%	63.2%	73.4%	60.8%	68.0%	75.2%	58.8%	61.6%	64.5%

Other	18.8%	23.7%	28.7%	18.6%	22.0%	25.4%	18.1%	19.1%	20.0%

Discussion and future steps

The maps created as part of this demonstration highlight that accurate maps of cocoa and plantations can be created for Ghana, but some considerable limitations exist. When mapping cocoa and large-scale industrial monoculture plantations, we encountered two primary limitations: a) limited historical remote sensing imagery and b) limited historical reference data for calibration and validation of the maps. These two limitations are considerable. The resulting maps created here show that 2015 maps were the most accurate and covered the most area. These are maps for which there is a significantly larger library of reference data. 2015 is also the only time period with PALSAR data available, although as noted above, the independent variables derived from PALSAR were among the least predictive. These results highlight that the development of spatially detailed and accurate historical maps of cocoa and plantations for the reference period is challenging. This challenge is even more apparent when moving from static land cover maps to land cover change maps. When deriving land cover change statistics, errors in the combined static maps are compounded, often resulting in very high uncertainty in land cover change. Moving forward in time, the primarily limitations to developing these maps will fade. Operational RADAR sensors have been launched by JAXA (e.g. PALSAR) and ESA (e.g. Sentinel 1), while additional optical sensors are coming online as well (e.g. Sentinel 2A and B). Field campaigns to observe and record the boundaries and characteristics of cocoa and monoculture plantations can be designed and deployed at regular intervals. The growing library of reference data will result in improved maps for the years to come.

It is also important to note that the final maps created here are only as accurate as the reference data used to create them. While we used more than 50 digitized polygons of cocoa as reference for the 2015 map, we relied on many digitized polygons generated via visual interpretation of high resolution optical data on Google Earth Pro. While these areas visually match the field surveyed cocoa farms, additional uncertainty remains. In particular, fallow areas may appear similar to young cocoa farms in the high resolution imagery. If a mistake in classification is made at the FRL, these errors will propagate through to the final maps.

A parallel question exists that can guide the evaluation of whether or not to pursue the mapping of cocoa and monoculture plantations. What are the emission factors associated with conversion of forest to a) cocoa and b) monoculture plantations (oil palm, rubber, and citrus)? Are the emission factors for these conversion fates significantly different? The answer to this question informs the decisions regarding the value of separating these tree crop types. If the emission factors for these three fates are largely the same, separating the three plantation types provides little additional value, and effort should be put elsewhere. If the emission factors differ, value can be gained from accurately separating the three plantation types, and this mapping is worth substantial effort.

In summary, while this analysis highlights that it is possible to discriminate cocoa and monoculture plantations from forest, this successful discrimination requires access to data that are not abundant during the reference period, including cloud- and haze-free moderate resolution optical data, L- and C-band RADAR data, and an extensive library of reference data.

Recommended additional analysis and improvements to the process

The maps created here do not have a minimum unit size below the pixel resolution. It may be appropriate to eliminate plantations under a certain size and classify these as forest.

Texture metrics, including standard deviation and spatial co-occurrence, were generated from a 90 x 90 meter moving window. These texture metrics as generated here, failed to improve the classification performance, most likely because the spatial scales of the features on the landscape (e.g. tree crops, roads) are often smaller than the 90 m scale offered by this texture analysis. We propose as an improvement, the use of the Landsat 15 meter panchromatic band for assessing texture.

Via JAXA, we acquired quad pole fine beam PALSAR backscatter data at 10 m spatial resolution for a subset of southern Ghana. The additional spatial resolution and polarity are likely to produce more accurate classification results. We recommend a further exploration of the improvements likely provided by the inclusion of quad pole radar data. While these additional activities will not improve FRL because radar data are not ubiquitous during the reference time period, radar data is likely to play a large role in forest monitoring in the tropics in the years to come due to a proliferation of sensors and an insensitivity to cloud cover.

Software and Training Description

Stephen Hagen and Lindsay Melendy traveled from the AGS offices in New Hampshire, USA to Kumasi, Ghana to conduct a workshop on 11-13 July 2016. The workshop was conducted at the Forestry Commission offices with approximately 25 participants from Ghana. The workshop was designed to communicate and discuss the initial results of the cocoa and plantation mapping, as well as install software and train the attendees in how to use the software for land cover mapping.

The workshop opened with introductions and high level discussions of how the maps created via this analysis fit into Ghana's overall needs as part of the Carbon Fund project. During the opening talks and discussions, the training team installed the required software on the participants' computers. The software installation included VirtualBox which then ran an Ubuntu 16.04 operating system. The workshop continued with an overview description of how the mapping was conducted, and a detailed description of each step of the process. During the evening of Day One, the AGS team worked to resolve some technical issues preventing the software from running on some computers.

Day Two included hands-on use of the software for mapping land use by the participants. Frequent discussions regarding cocoa definitions and potential challenges for this type of mapping were engaged. Day Three concluded the hands-on training, and an introduction to uncertainty assessment using Olofsson et al. 2014 as a guide was presented. The workshop concluded with more robust discussion. The AGS team made two primary recommendations to the workshop participants: 1) install the software presented here on a robust server with multiple processors and substantial RAM; 2) train 1-3 team members to be proficient in python programming. The recommendations were based on the fact that 1) the software used here requires substantial memory and was designed to run on powerful servers instead of laptops; 2) the software as implemented is designed to work for a narrow range of applications and can be edited to fit a broad range of applications.

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ANNEX C: LOGGING MEASUREMENT STANDARD OPERATING PROCEDURE TO UPDATE LOGGING EMISSION FACTORS

Standard Operating Procedures for Estimation of Carbon Stock Damage from Selective Logging in Ghana

Timothy RH Pearson, Felipe M Casarim, Sarah Walker, Alexandre Grais, Gabriel Sidman and Sandra Brown

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Contents

Introduction and How to Use this Document

The active and important role vegetation and soil play in the global carbon cycle and global climate change is now internationally recognized. Vegetation and soil can act as both a net source and a net sink of greenhouse gas (GHG), depending on how the land is managed. Alterations in land use management techniques that result in changes to net GHG emissions are now a significant component to the regulatory and voluntary actions taking place globally to combat climate change.

The purpose of this document is to provide standard field measurement approaches to assist in quantifying the amount of carbon stored within the various organic pools found within a landscape. The methods presented in each Standard Operating Procedure (SOP) have been developed over time by foresters and ecologists to accurately and efficiently estimate carbon stocks.

The SOPs are grouped by purpose. The first set of SOPs are general and can be used for many field measurement goals. A set of SOPs are also presented on the measurement of all the carbon pools. These can be used to estimate the standing stock of a carbon pool within a stratum. Another set of SOPs are presented to estimate the emissions resulting from selective logging. Various SOPs are also presented on estimating canopy cover. These SOPs should only be used when the purpose of data collection is known.

This manual *does not* specify guidance on stratification, sampling design, sampling intensity, the spatial distribution of sampling points, pool measurement selection, or the methods needed to transform field measurement data into carbon stock estimates. Therefore, additional guidance is required prior to any field data collection.

The SOPs present a *generic* approach that will be appropriate for most land cover types, ecosystems, and locations. However, all the field measurement methods presented in this document may require adaptation for the specific ecosystem, land cover, and vegetation type in the location where sampling will take place.

The SOP manual is also *not specific* to any regulatory or voluntary market standard such as the Clean Development Mechanism (CDM), Climate Action Reserve (CAR), American Carbon Registry (ACR), Verified Carbon Standard (VCS), CarbonFix, or PlanVivo.

Therefore, it is imperative that methods presented here are adapted into a specific SOP manual, developed for a specific field measurement campaign. The particular adaptations required should be conducted by a forester or ecologist with detailed knowledge in field carbon stock measurement and in the particular carbon market regulatory requirements.

In addition, the SOPs should not be conducted without receiving extensive field training in the measurement methods performed by a qualified forester or ecologist.

It is expected that this manual will be updated overtime as the carbon market changes and as terrestrial carbon science evolves. Therefore, it is recommended that prior to use, users visit Winrock International's website to determine if a more recent version is available at www.winrock.org/ecosystems

SOP Field safety

No matter what activities are engaged in or where they are carried out, *safety is the first priority* and all precautions must be well thought out in advance and then strictly adhered to. Planned field activities must remain flexible and allow for adjustments in response to on-the-ground assessments of hazards and safety conditions. Accordingly, field personnel must be vigilant and always avoid unnecessary risks.

Field crew members in particular must be well prepared. It is recommended that personnel engaging in field activities hold general first aid training and if possible training in CPR.

The following guidelines will apply to all field-based activities:

- Mandatory buddy system. Field crews will include no less than two people who must be directly accompanying each other for the entire duration of field work. Ideally field crews should include a minimum of three people; in case of an accident resulting in injury one person may leave to seek help while another person stays with the injured crew member.
- For each day in the field, specific location and scheduling information must be logged in advance with a point person who can be reached at any time during the anticipated duration of field work. While in the field, crews should check in with their designated point person once per day.
- Each independent crew must carry a radio, satellite phone or cell phone provided by the institution. Crews should make sure to check batteries each time before entering the field.
- Trip planning will include identification of the nearest medical facility and specific directions to reach that facility. When in areas with poisonous snakes, advance communication should

be made to verify that appropriate antivenins are available. Where applicable, hunting regulations should be checked with local state agencies prior to field work.

- Personnel will carry personal and institutional insurance cards with them at all times. As well, personnel will carry identification and, if possible, institutional business cards at all times.
- Field crews will carry a first aid kit with them at all times. First aid kits should contain Epinephrin/Adrenalin or an antihistamine for allergic reactions (e.g. bee/wasp stings). Sun block and insect repellent should be carried in the field.
- Where poisonous snakes are common, snake chaps are recommended. In the event of snake bite, the victim should be taken immediately to a medical facility. Conventional "snake bite kits" (e.g. suction cups, razors) have been proven ineffective or even harmful and should not be used.
- Basic field clothing should be appropriate for the range of field conditions likely to be encountered. This will include: sturdy boots with good ankle support or rubber boots, long sleeves and pants, rain gear, and gloves. Blaze orange (vest or hat) is recommended when and where hunting may be taking place. Where necessary, to avoid extended contact with plant oils, ticks, and/or chiggers, a change of clothes should be made at the end of each day in the field and field clothes should not be reworn without first laundering.
- Ensure personnel stay sufficiently hydrated and carry enough clean water for the intended activity. Carry iodine tablets or other water purification tablets in case there is a need to use water from an unpurified source.
- Heightened caution should be given while operating any motor vehicle, particularly on backcountry roads where conditions are unreliable and rights-of-way are often not designated or adhered to. ATVs should always be operated at low speeds (<15 mph).
- Some plots may be too hazardous to sample. Situations include: plot center on a slope too steep to safely collect data (i.e., >100% slope or on a cliff); presence of bees; volcanic activity; illegal activities; etc. When hazardous situations arise, a discussion should be conducted among the team members to assess the situation.

SOP Quality Assurance/Quality Control

Those responsible for aspects of data collection and analysis should be fully trained in all aspects of the field data collection and data analyses. Standard operating procedures should be followed rigidly to ensure accurate measurement and remeasurement. It is highly recommended that a verification document be produced and filed with the field measurement and calculation documents that show that QA/QC steps have been followed.

Quality Assurance

Data collection in field:

During all data collection in the field, the crew member responsible for recording must repeat all measurements called by the crew member conducting the measurement. This is to ensure the measurement call was acknowledged and that proper number is recorded on the data sheet. In addition, all data sheets should include a 'Data recorded by' field with the name of the crew member responsible for recording data. If any confusion exists, the transcribers will know which crew member to contact.

After data is collected at each plot and before the crew leaves the plot, the crew leader shall double check to make sure that all data are correctly and completely filled. The crew leader must ensure the data recorded matches with field conditions, for instance, by verifying the number of trees recorded.

Data sheet checks:

At the end of each day all data sheets must be checked by team leaders to ensure that all the relevant information was collected. If for some reason there is some information that seems odd or is missing, mistakes can be corrected the following day. Once this is verified and potential mistakes checked, corrected data sheets shall be handed over to the person responsible for their safe keeping while the crew is still in the field. Data sheets shall be stored in a dry and safe place while in the field. After data sheets have been validated by crew leaders, the data entry process can commence.

Field data collection Hot Checks:

After the training of field crews has been completed, observations of each field crew and each crew member should be made. A lead coordinator shall observe each field crew member during data collection of a field plot to verify measurement processes and correct any errors in techniques. It is recommended that the crew chiefs switch to a different crew to ensure data collection procedures are consistent across all field crews. Any errors or misunderstandings should be explained and corrected. These types of checks should be repeated throughout the field measurement campaign to make sure incorrect measurement techniques have not started to take place.

Data Entry checks:

To ensure that data is entered correctly, the person entering data (whether during fieldwork or after a return to the office) will recheck all of the data entered and compare it with the original hard copy data sheet before entering another sheet. It is advised that field crew leaders either enter the data, or participate in the data entry process. Crew leaders have a good understanding of the field sites visited, and can provide insightful assistance regarding potential unusual situations identified in data sheets. Communication between all personnel involved in measuring and analyzing data should be used to resolve any apparent anomalies before final analysis of the monitoring data can be completed. If there are any problems with the plot data (that cannot be resolved), the plot should not be used in the analysis.

Quality Control

Field measurement error estimation

A second type of field check is used to quantify the amount of error due to field measurement techniques. To implement this type of check, a complete re-measurement of a number of plots by people other than the original field crews is performed. This auditing crew should be experienced in forest measurement and highly attentive to detail. One gap per concession should be randomly or systematically chosen to be re-measured. Field crews taking measurements should not be aware of which gaps will be re-measured whenever possible.

After re-measurement, data analysis is conducted and biomass estimates are compared with estimates from the original data. Any errors discovered could be expressed as a percentage of all plots that have been rechecked to provide an estimate of the measurement error.

For all the verified plots:

$$\text{Measurement Error (\%)} = \left| \frac{(\text{t C/ha of measured plot} - \text{t C/ha of remeasured plot})}{\text{t C/ha of remeasured plot}} \times 100 \right|$$

This error level will be included in the carbon stock reporting.

Data Entry quality control check:

After all data has been entered into computer file(s), a random check shall be conducted. Sheets shall be selected randomly for re-checks and compared with data entered. Ten percent of all data sheets shall be checked for consistency and accuracy in data entry. Other techniques such as data sorting and verification of resulting estimates shall be employed to ensure data entered properly corresponds to field sites visited. Personnel experienced in data entry and analysis will be able to identify errors especially oddly large or small numbers. Errors can be reduced if the entered data is reviewed using expert judgment and, if necessary, through comparison with independent data.

Framework for estimation of carbon stock damage from selective logging

Selective logging is the harvesting of a proportion of the trees in a stand or forest. Selective logging may be used to manage even or uneven-aged stands with the goal of protecting forest soils, maintaining or improving wildlife habitat, increasing site productivity, or improving tree species diversity. There will be auxiliary damage to the forest carbon stock during selective logging; from broken branches on remaining trees to the creation of new roads and the clearing of areas for logging decks. The calculation of forest carbon stock damage from selective logging involves the use of several SOPs.

Estimation of carbon stock damage from selective logging involves the following SOPs:

1 LOCATING FELLED TREES
2 CARBON STOCK DAMAGE DUE TO TREE FELLING
3 AREA OF CANOPY OPENING
4 CROWN AREA FROM THE GROUND
5 CARBON STOCK DAMAGE DUE TO LOGGING EXTRACTION

Locating felled trees

Field Equipment:

GPS receiver

Locating felled trees in a dense forest is not always an easy job. It is best to have a person familiar with the logging process in the area to act as a guide. If a guide is not available, it is best to start at a logging deck and systematically walk all skid trails radiating out from the logging deck. One systematic method is to use the clockwise method, start with a skid trail at the north or nearest to the northern direction from the center of the logging deck. Next proceed with the next closest skid trail in a clockwise direction. Look for signs of felled trees such as stumps, broken or bent branches in the standing trees, or canopy openings.

Carbon stock damage due to tree felling

Field Equipment:

Flagging

GPS receiver

DBH tapes

DME or other distance measuring equipment
Machete or knife
Permanent marking pen
Compass
Large diameter calipers
Laboratory Equipment:
Drying oven
Laboratory scale

This SOP describes the methodology for estimating the biomass remaining in the forest that has been selectively logged. The concept underlying these methods is based on the "Gain-Loss" method described by the IPCC (2006). Measurements in the "Logging Plots" should be conducted soon after the tree is felled (within approximately 3 months).

Estimating carbon emissions due to selective logging practices consists of an investigative activity, where field technicians must take accurate measurements. Amongst the measurements taken in the field, **DBH** and **dimensions of the removed log** are especially **important**. These measurements must be accurate and reflect the real conditions in the field. It is not always possible to measure DBH because part of the bole where one would measure it (see 'Measuring Trees') is removed. Thus, when DBH measurement is not possible, other measurements must be used to extrapolate to DBH.

Measurements on felled tree:

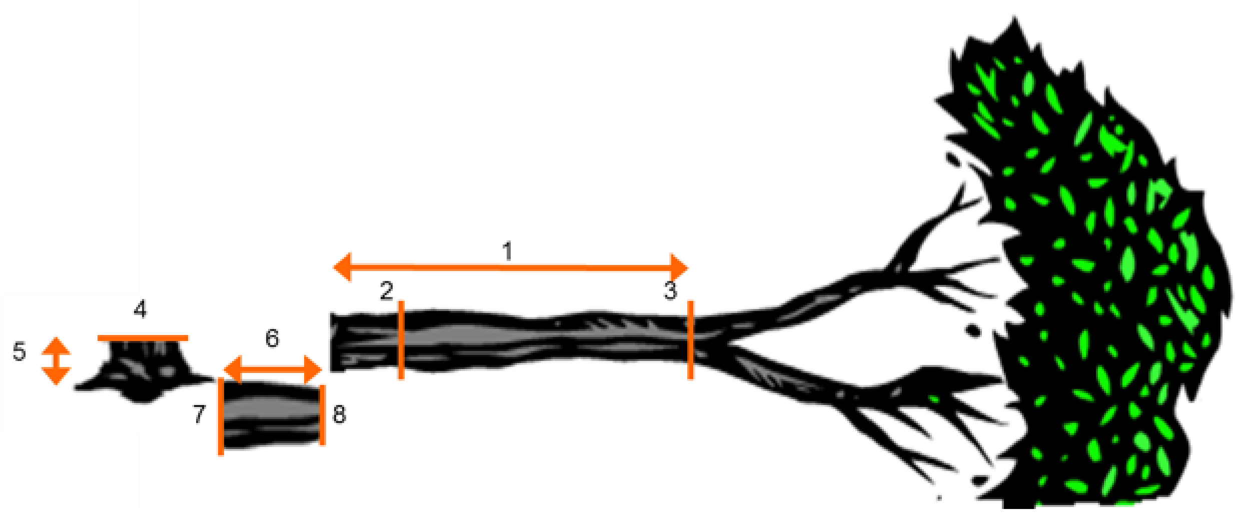
1. Locate stump and crown of logged tree. Be sure to verify that the crown is from the selected stump by determining the angle of the tree fall, species and distance from stump. Search the surrounding area for other potential stumps.
2. Measurements on the stump of the tree (should be taken with calipers):
    a. Measure the height of the remaining stump (H_{Stump}).
        i. If stump is taller than 1.3m and not buttressed, measure DBH.
    b. Measure the diameter (*d*) at the top of the stump (d_S). This measurement is very important as measurement of DBH is often not possible.
        i. If the tree is not buttressed, measure the diameter as in a tree (wrapping the tape around the stump).
        ii. If the tree is buttressed, measure the height of the buttress ($H_{Buttress}$) and the diameter at the top of the buttress, which can be either top of the

stump or top of a piece that was cut from bottom of the log. Measure diameter of buttressed tree using a watch and taking three measurements total: 12-to 6, 2 to 8, 4 to 10,where 12 o'clock always points due north when diameter measurement is horizontal, or upward to the sky when diameter is vertical (i.e. piece lying on the ground). The average of these three measurements will be the diameter of the stump (d_S)

3. If a section(s) of the bole of the tree is cut and left in the forest (i.e. will not be removed), measure the length (l_{Piece}) and the diameters at the bottom ($d_{Piece-B}$) and top of the piece ($d_{Piece-T}$). If piece is buttressed, measure diameter using a watch and taking three measurements total: 12-to 6, 2 to 8, 4 to 10, where 12 o'clock always points due north when diameter measurement is horizontal, or upward to the sky when diameter is vertical (i.e. piece lying on the ground).
4. Measure the diameter at the top cut where the log was removed (d_T).If diameter of top of the tree is irregular, measure diameter using a watch and taking three measurements total: 12-to 6, 2 to 8, 4 to 10, where 12 o'clock always points upward to the sky.
5. Measure the length of the log (l_{Log}). The length of the log is the distance between the edge of the stump and the top cut as shown in figure below. This distance can often be the distance between the top of the piece and the bottom of the crown left in the forest. This measurement is crucial and requires high level of accuracy, even though it may require some judgment.

   Important:

   a. If tree has not yet been removed, field crew must assess location where bole will be cut at the bottom (if lower portion of bole will not be taken as a log) and at the top (at the base of the crown), and then measure this distance, which represents the length of the log. Expert knowledge will be necessary to accurately ascertain where the cuts will occur – this should be attained by having team members who have previously participated in tree harvests.
   b. If tree has moved during or after felling (i.e. slid due to slope, dragged with skidder to facilitate consecutive cuts, etc), field crew must assess the distance it moved (i.e. distance from stump or top of the piece to bottom of the log) to accurately measure the length of the log. The distance the felled tree has moved can be often identified by saw-dust vestiges in the forest floor indicating wood cutting, dragging marks from the bole scrapping the forest floor, dragging markings from skidder or skidder-cable on the forest floor, etc.
6. Measure the avoidable merchantable waste in the main stem after bole branches off, from the top cut to the minimum diameter accepted by the mill. Measure the length (l_{AMW}) and the top diameter of this piece (d_{AMW-T}).



Measurements required in a logging plot.

Where:

1. Length of the log (l_{Log})
2. DBH
3. Diameter at the top cut (d_{Top})
4. Diameter of the stump (D_{Stump}) (and diameter of bottom of the log if no piece present – d_{Bottom})
5. Height of the stump (H_{Stump})
6. Length of the piece (l_{Piece})
7. Diameter of the bottom of the piece ($d_{Piece\text{-}B}$)
8. Diameter of the top of the piece ($d_{Piece\text{-}T}$)(and diameter of bottom of the log – d_{Bottom})

Different scenarios may be faced by field crews when implementing the "Logging Plots". Thus a diagram outlining the different possibilities and providing the appropriate measurements to conduct under such circumstances is provided below.

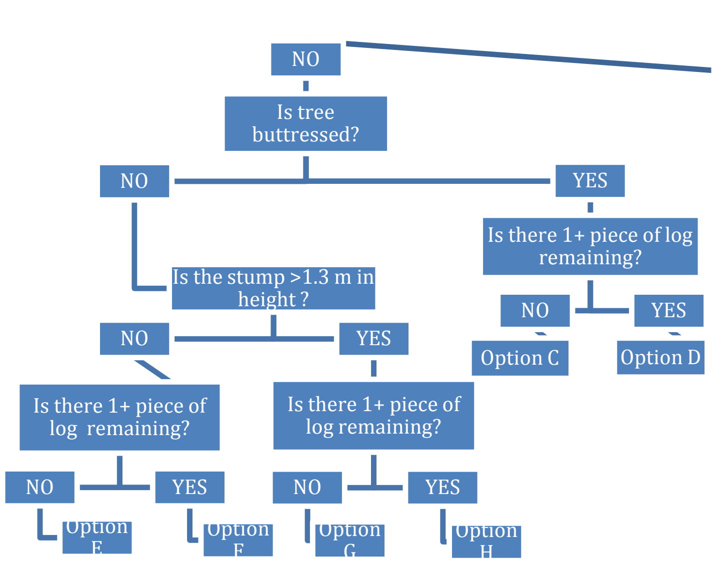


Diagram of different possibilities faced by field crew.

Below are the measurement field crew should take from felled tree under the different circumstances encountered in the field.

<u>Option A</u>

Take measurements: 1, 2, 3, 4, 5,

<u>Option B</u>

Take measurements: 1, 2, 3, 4, 5, and, if possible, measure the height of the buttress ($H_{Buttress}$).

<u>Option C</u>

Take measurements: 1, 4, 5, Also estimate the length of the log (3) and, if possible, measure the height of the buttress ($H_{Buttress}$).

<u>Option D</u>

Take measurements: 1, 4, 5, 6, 7, 8. Also estimate the length of the log (3) and, if possible, measure the height of the buttress ($H_{Buttress}$).

<u>Option E</u>

Take measurements: 1, 4, 5. Also estimate the length of the log (3).

Option F

Take measurements: 1, 4, 5, 6, 7, 8. Also estimate the length of the log (3) and, if possible, measure the DBH (2) in piece of log.

Option G

Take measurements: 1, 2, 4, 5. Also estimate the length of the log (3) and, if possible, measure DBH (2).

Option H

Take measurements: 1, 2, 4, 5, 6, 7, 8. Also estimate the length of the log (3), if possible, measure DBH (2).

Incidental damage measurements:

When a timber tree is felled, it incidentally damages the residual stand in two main ways: 1) by knocking down, uprooting or breaking other trees and 2) breaking off large branches of surviving trees. Measurements of incidental damage should be conducted as follow:

1. Walk along the area where timber tree fell in a clockwise direction starting from the stump, and identify all trees significantly damaged and branches broken off due felling the timber tree.
    a. Measure the DBH (≥10 cm) and note the species of all trees that are either uprooted or are snapped 1m or less above ground. Follow good practices outlined in 'SOP for Measurements of Trees' for measuring DBH. Do not measure any pre-existing dead trees.
        i. Classify the damaged trees into the following classes:
            1. Uprooted, lying on ground (G)
            2. Crown snapped off (S)

        Note: Bent or leaning trees are conservatively assumed to not be dead and will survive.

    b. Measure diameter of all significant braches (base diameter ≥10 cm) that have been damaged by felling the timber tree:

21. Note: It is very important that any large branches on the forest floor be clearly identified as originating from a surviving tree and not from an already measured damaged tree to prevent double counting. Efforts must also be taken to ensure branches were snapped

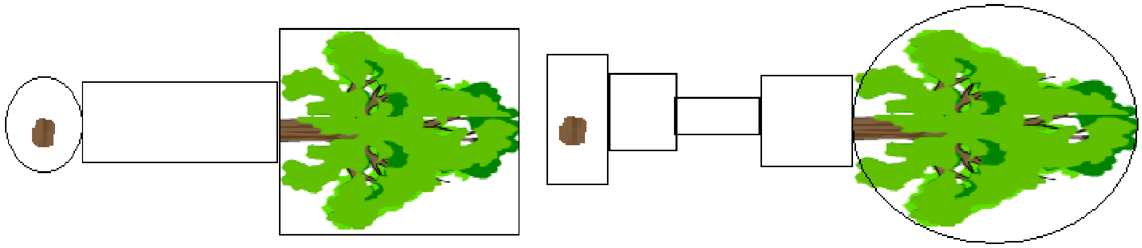
during tree fall and do not represent down dead wood predating the harvest. Such branches should be sound, and have evidence of being relatively recently fallen (e.g. presence of leaves, twigs, complete bark, etc.).

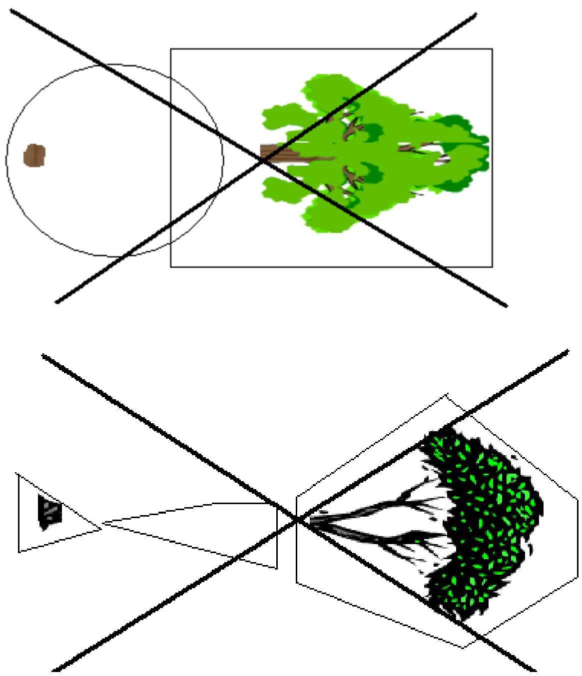
Area of canopy opening

Field Equipment:
GPS receiver
Laser Range Finder

This SOP is used to estimate the area of canopy opening created when a tree is selectively logged in a forest. This method will be most accurate if done relatively soon after the tree is cut. This will most often be done in conjunction with 'SOP Carbon stock damage due to tree felling'.

1. Locate stump and crown of logged tree. Be sure to verify that the crown is from the selected stump by determining the angle of the tree fall, species and distance from stump. Search the surrounding area for other potential stumps.
2. Walk around the entire gap, locating every section of gap formed. Mentally divide the gap into different *non-overlapping* ovals or rectangles. Shapes must either be either: oval, circle, rectangle or square. There must be direct vertical penetration of light to the forest floor to qualify as gap. They cannot be complex shapes unless detailed angles are taken). Draw shapes onto data sheet.
3. Measure and record the length and width or diameter of the appropriate shape. **Remember** – to measure the area of an oval one must measure diameter of major axis *and* minor axis.





Carbon stock damage due to log extraction

Field Equipment: GPS receiver Laser Range Finder or Measuring tape

This SOP describes the methods used to estimate the carbon damages from the construction infrastructure used to remove logs out of the forest, such as: skid trails, new haul roads, and logging decks. The methods will be most accurate if done soon after the tree is cut. This will most often be done in conjunction with 'SOP Carbon stock damage due to tree felling'.

<u>Assumptions</u>

In this SOP, skid trail is a pathway travelled by ground skidding equipment while moving trees or logs to a landing. A skid trail differs from a skid road in that the ground surface is mainly untouched by the blades of earth moving machines. A logging deck is the centralized location where logs are gathered, delimbed and cut to length if necessary, and loaded on to log trucks for transport. A road is used by log trucks to take logs from the logging deck and ends at a pre-existing road or highway.

<u>Skid trails:</u>

In areas where skid trails are wide and completely cleared of vegetation:

1. Measure width of all skid trails at various random locations (at least 20 measurements per skid trail)
2. Measure DBH and species of all trees along the side of the skid trails that are clearly damaged (snapped or uprooted) due to skid trails construction.
3. Use tracking feature of the GPS to track entire length of skid trails.
    a. Collect waypoints at beginning and end of skid trail.
4. Calculate the area of skid trails by multiplying the average width by the total length
5. Multiply area of skid trails by carbon stock of stratum where skid trail is constructed. Note: This carbon stock impacted by skid trails is often smaller the total forest carbon stocks as skidder do not kill all trees to haul logs out of the forest, especially the trees with large DBH (e.g. DBH>50cm).
6. Divide result from 4 by cubic volume extracted from the gaps associated with the measured skid trail
7. Average across the skid trails measured in the concession

Skid trail in Guyana **Skid trail in Brazil**

In areas where skid trails are narrow paths into the forest with live vegetation on the ground:

1. Measure the DBH and species of all trees clearly damaged (snapped or uprooted) due to skid trails construction.
2. Use tracking feature of the GPS to track entire length of skid trails.
    a. Collect waypoints at beginning and end of skid trail.
3. Divide result from 2 by cubic volume extracted from the gaps associated with the given skid trail.

4. Average across the skid trails measured in the concession
   22.

Logging decks:

1. Measure at least 20 logging decks per concession by breaking down the area of the logging deck into simple geometric shapes (square, rectangle or circle). Draw sketch of the shape of entire logging deck in datasheet. Measure the sides/diameters of all shapes imagined, and record measurements in respective place (i.e. aside of drawn geometric shape) on the datasheet.
2. Multiply area of deck by carbon stock of stratum where deck is constructed.

Logging deck in Guyana

Roads

To calculate the impact of logging roads aerial imagery can be used to correlate area of roads with a measured stock for unlogged forest per unit area. If aerial imagery is not available:

1. Measure width of all haul roads at various random locations
2. If length of haul roads are not reported. Use tracking feature of the GPS to track entire length of roads. Otherwise, use reported length of logging roads.
   a. Collect waypoints at beginning and end of haul road.
3. Calculate the area of roads by multiplying the average width by the total length.
4. Multiply area of road by the carbon stock of stratum where road is constructed.
5. Divide result from 4 by cubic volume extracted in the area where the roads are found for that year.

Logging road in Guyana

TIMBER TREE MEASUREMENTS

Date________________________

Plot ID #:___________________Location: _________________ Coordinate System:

Crew chief: __________________ Data recorded by: ___________________ # people in crew: _________

Start Time: _________________End time: __________________Total Time: _____________minutes

Camera Number: ______________ Photo Number(s):________________

Forest type

Additional notes describing plot area:

Timber Tree 1

Species: _______________ GPS Accuracy: _____ (m)

GPS Coordinarte: E: ____________N: ____________

Timber Tree 2

Species: _________________ GPS Accuracy: _____ (m)

GPS Coordinarte: E: ____________N: ___________

Tree Buttressed:	☐ Yes ☐ Not			Tree Buttressed:	☐ Yes ☐ Not	
Height of the buttress ($H_{Buttress}$)	______	(cm)		Height of the buttress ($H_{Buttress}$)	______	(cm)
Diameter of stump top (d_S):	______	(cm)		Diameter of stump top (d_S):	______	(cm)
Height of the stump (H_S):	______	(cm)		Height of the stump (H_S):	______	(cm)
DBH(dbh):	______	(cm)		DBH(dbh):	______	(cm)

Log Section 1:	diam. bottom ($d_{Piece-B}$):	_______	(cm)		Log Section1:	diam. bottom ($d_{Piece-B}$):	_______	(cm)
	diam. top($d_{Piece-T}$):	_______	(cm)			diam. top($d_{Piece-T}$):	_______	(cm)
	length (l_{Piece}):	_______	(cm)			length (l_{Piece}):	_______	(cm)
Log Section 2:	diam. bottom ($d_{Piece-B}$):	_______	(cm)		Log Section 2:	diam. bottom ($d_{Piece-B}$):	_______	(cm)
	diam. top($d_{Piece-T}$):	_______	(cm)			diam. top($d_{Piece-T}$):	_______	(cm)
	length (l_{Piece}):	_______	(cm)			length (l_{Piece}):	_______	(cm)
	Length of Log (l_{Log}):	_______	(m)			Length of Log (l_{Log}):	_______	(m)
	Log:	☐ Present ☐ Absent				Log:	☐ Present ☐ Absent	
	Diameter at top cut (d_T):	_______	(cm)			Diameter at top cut (d_T):	_______	(cm)
	Length of avoid. merchant waste (l_{AMW})	_______	(m)			Length of avoid. merchant waste (l_{AMW})	_______	(m)
	Diam. top of avoid. merchant waste(d_{AMW-T})	_______				Diam. top of avoid. merchant waste(d_{AMW-T})	_______	

Sketch of Canopy Gap: Canopy Opening Dimensions: ________________________________

DAMAGED TREES MEASUREMENTS

Damage type: (S) snapped, (U) uprooted, or (B) branch (if larger than 10 cm in diameter)

Species	**DBH**	**Type**	**Species**	**DBH**	**Type**	**Species**	**DBH**	**Type**	**Branches**	**D1**	**D2**	**Length**

SKID TRAIL DATA SHEET

Skid Trail ID: _________________ Location: _________________ Date: ______/_______/_______

Crew Chief: _________________ Coordinate System:

Skid Trail Widths: (m)

Fatally Damaged trees: (S) snapped, (U) uprooted

Species	DBH	Type	Species	DBH	Type	Species	DBH	Type	Species	DBH	Type

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Skid Trail ID: ________________ Location: ________________ Date: ______/_______/_______

Crew Chief: ________________ Coordinate System:

Skid Trail Widths: (m)

Fatally Damaged trees: (S) snapped, (U) uprooted

Species	DBH	Type	Species	DBH	Type	Species	DBH	Type	Species	DBH	Type

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Skid Trail ID: _________________ Location: _________________ Date: ______/_______/_______

Crew Chief: _________________ Coordinate System:

Skid Trail Widths: (m)

Fatally Damaged trees: (S) snapped, (U) uprooted

Species	DBH	Type	Species	DBH	Type	Species	DBH	Type	Species	DBH	Type

LOGGINGDECK DATA SHEET

Date: __________/_________/_________

Logging Deck ID: __________________________ Location: ________________________

Polygon ID: ________________ (Using polygon feature of GPS) **OR**

Coordinate. System: GPS Waypoint E: __________________ N:___________________

Logging Deck Dimensions: ________________________Sketch of Logging Deck:

Logging Deck ID: __________________________ Location: ________________________

Polygon ID: ________________ (Using polygon feature of GPS) **OR**

Coordinate. System: GPS Waypoint E: ________________ N:_________________

Logging Deck Dimensions: _____________________Sketch of Logging Deck:

Logging Deck ID: _______________________ Location: _____________________

Polygon ID: ______________ (Using polygon feature of GPS) **OR**

Coordinate. System: GPS Waypoint E: ________________ N:_________________

Logging Deck Dimensions: _____________________Sketch of Logging Deck:

Logging Deck ID: _______________________ Location: _____________________

Polygon ID: ______________ (Using polygon feature of GPS) **OR**

Coordinate. System: **WGS84** GPS Waypoint E: ________________ N: _________________

Logging Deck Dimensions: _____________________Sketch of Logging Deck:

Logging Deck ID: _______________________ Location: _____________________

Polygon ID: ______________ (Using polygon feature of GPS) **OR**

Coordinate. System: GPS Waypoint E: ________________ N:_________________

Logging Deck Dimensions: _____________________Sketch of Logging Deck:

ROAD DATA SHEET

Road Track ID: ________________Location: ________________ Date: _____/_____/_______

Road Type: __________________Crew Chief: __________________Coordinate System:

Road Width: (m)

Road Track ID: _________________Location: _________________ Date: _____/_____/_______

Road Type: ___________________Crew Chief: ___________________ Coordinate System:

Road Width: (m)

Road Track ID: _________________Location: _________________ Date: _____/_____/_______

Road Type: ___________________Crew Chief: ___________________ Coordinate System:

Road Width: (m)

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