GHANA'S NATIONAL FOREST REFERENCE LEVEL

2001 - 2015

Forestry Commission

GhREDD+

GHANA FOREST REFERENCE LEVEL (FRL) / FOREST REFERENCE EMISSIONS LEVEL (FREL) 2001 - 2015

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LIST OF ABBREVIATIONS AND ACRONYMS

AGB	Above-Ground Biomass
AD	Activity Data
AFOLU	Agriculture, Forestry and Other Land Use
AR2	IPCC's Second Assessment Report
BGB	Below-Ground Biomass
BUR	Biennial Update Report
C	Cropland
C stocks	Carbon Stocks
CANN	Annual Crops
CE/OF	Collect Earth/Open Foris
CF	Carbon Fraction
CFA	Fallow
CfRN	Coalition for Rainforest Nations
CH_4	Methane
CI	Confidence Interval
CNES	Centre National D'Etudes Spatiales (National Centre for Space Studies)
CO_2	Carbon dioxide
COP	Conference of the Parties
CPER	Perennial Cropland
CSDS	Cocoa Sector Development Strategy
CSIR-FORIG	Council for Scientific and Industrial Research – Forestry Research Institute of Ghana
CSIR-SRI	Council for Scientific and Industrial Research –Soil Research Institute
d.m.	Dry Matter
DOM	Dead Organic Matter
DRYFIRE	Dry Semideciduous Fire Zone
DRYINNER	Dry Semideciduous Inner Zone
DW	Deadwood
EF(s)	Emission Factor(s)
ETF	Enhanced Transparency Framework
F	Forest Land
FAO	Food and Agriculture Organization (of the United Nations)
FC-RMSC	Forestry Commission – The Resource Management Support Centre
FIRE	Fire Disturbance
FLEGT	Forest Law Enforcement, Governance and Trade
FOLU	Forestry and Other Land Uses
FPP	Forest Preservation Programme
FREL/FRL	Forest Reference Emission Level / Forest Reference Level
G	Grassland

GFC	Ghana Forestry Commission
GCFRP	Ghana Cocoa Forest REDD+ Programme
GHG	Greenhouse Gas
GHGI	Greenhouse Gas Inventory
GLs	Guidelines
GoJ	Government of Japan
GoG	Government of Ghana
GRASS	Woody and Non-woody Grassland
GRS	Ghana REDD+ Strategy
GSIF	Ghana Strategic Investment Framework
GWP	Global Warming Potential
Ha	Hectare
HFZ	High Forest Zone
HWP	Harvested Wood Product
IPCC	Intergovernmental Panel on Climate Change
KNUST	Kwame Nkrumah University of Science and Technology
km^2	Square Kilometer
LI	Litter
LCDS	Low Carbon Development Strategy
LIDAR	Light Detection and Ranging
LULUC	Land Use, Land-Use Change
LULUCF	Land Use, Land-Use Change and Forestry
m^2	Square Meter
mm	Millimeter
MEVER	Moist Evergreen
MPG	Modalities, Procedures, and Guidelines
MRV	Measuring, Reporting, and Verification
MSEMSE	Moist Semideciduous South-East
MSEMNW	Moist Semideciduous North-South
n	Sample Size
NA	Not Applicable
NE	Not Estimated
N_2O	Nitrous oxide
NDCs	Nationally Determined Contributions
NDVI	Normalized Difference Vegetation Index
NE	Not Estimated
NFMS	National Forest Monitoring System
NGHGI	National Greenhouse Gas Inventory
NTFPs	Non-Timber Forest Products
NW	North West
O	Other Land

PA	Paris Agreement
QA/QC	Quality Assurance/ Quality Control
R	Root-to-Shoot Ratio
REDD+	Reducing Emissions from Deforestation;Forest Degradation; and the role of Conservation of Forest Carbon Stocks; Sustainable Management of Forests; and Enhancement of Forest Carbon Stocks
S	Settlements
SAV	Savannah
SBSTA	Subsidiary Body for Scientific and Technological Advice
SD	Standard Deviation
SE	South East
SET	Urban Areas
SFM	Sustainable Forest Management
SPOT	Satellite Pour l'Observation de la Terre (Earth Observation Satellite)
SOC (or SO)	Soil Organic Carbon
SOUTH	Southern Marginal
T1	Tier 1
T2	Tier 2
T3	Tier 3
TOA	Top of Atmosphere
TZ	Transition Zone
UNFCCC	United Nations Framework Convention on Climate Change
UPEVER	Upland Evergreen
W	Wetlands
WET	Flooded Lands
WETEVER	Wet Evergreen

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EXECUTIVE SUMMARY

Ghana on a voluntary basis submitted a Forest Reference Level (FRL) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2017 in response to the invitation by the Conference of Parties and in accordance with the provisions of decision 12/CP.17, paragraphs 7-17 and its annex and also in accordance with decision 13/CP.19 and in the context of results-based payments. During the submission and the ensuing technical assessment, Ghana noted of a revised submission of the FRL in later years when new methodologies or data sets are available to the country. Ghana understands that FRLs should be updated periodically as appropriate, taking into account new knowledge, new trends and / or new methodologies. It is in this regard and having accessed new methodology and datasets that Ghana seeks to make this new FRL submission voluntarily to the UNFCCC.

In the 2017 submission, the FRL proposed by Ghana was a national FRL which covered the activities "reducing emissions from deforestation", "reducing emissions from forest degradation" and "enhancement of forest carbon stocks", which are among the activities included in decision 1/CP.16, paragraph 70. The same activities (Deforestation, Forest Degradation and Carbon Stock Enhancements) are included in this submission though the activity data for the activities have changed. The FRL presented in 2017 was for the reference period 2001–2015 and based on a simple historical average approach. The FRL corresponded to 60,670,197 tonnes of carbon dioxide emissions equivalent per year. The submission in 2017 saw the country as a net emitter of CO_2.

The main difference between the submission in 2017 and this current one is seen in the approach for activity data generation. The 2017 FRL included deforestation estimates following a stratified area estimate approach. The landuse maps that were used for the stratified area estimate concern three change maps (2000-2010; 2010-2012; 2012-2015) created through post-classification (i.e. change is assessed by comparing independently created classifications for different dates). The current method uses interpretation of sample points on a systematic grid across the country with different levels of intensification (1x1 km, 2x2, 4x4 and 8x8 km grid) within the Collect Earth platform of OpenForis tools developed by the Food and Agriculture Organization of the United Nations.

The 2017 FRL also included a degradation estimate based on proxy data (e.g. timber extraction statistics, MODIS burned area, etc.) and an enhancement estimate based on national statistics on areas planted. This submission makes use of the Collect earth data used for estimation of deforestation to also calculate for degradation and enhancement of carbon stocks particularly Forest Lands remaining Forest Lands.

REDD+ Activity	Activity data		Emission factor	
	FREL 2017	FREL 2021	FREL 2017	FREL 2021
Deforestation	Landsat satellite imagery (T3)	Sample points interpreted in Collect Earth using high-resolution imagery such as; planet data (5m resolution), Bing maps, and Google Earth Engine to precisely assign attribution to various sample points.	Field data collected by GFC (T3), Peer-reviewed published literature: Kongsager et al. (2013) (T2), IPCC defaults i.e. Tier 1 (T1)	Field data collected by GFC (T3), IPCC defaults i.e. Tier 1 (T1)
Degradation	Logging: Forestry Commission data, illegal logging: peer reviewed paper(Hansen et al. (2012) for Ghana, fire: MODIS burned area product, fuelwood: Global dataset WISDOM	Sample points interpreted in collect earth using high-resolution imagery such as; planet data (5m resolution), Bing maps, and Google Earth Engine to precisely assign attribution to various sample points.	field data for legal logging, T1 assumptions for fire emissions, IPCC defaults for fuelwood	Field data from GFC
Enhancement	GFC field data	Sample points interpreted in collect earth using high-resolution imagery such as; planet data (5m resolution), Bing maps, and Google Earth Engine to precisely assign attribution to various sample points.	Peer-reviewed published literature and IPCC defaults	Peer-reviewed published literature and IPCC defaults

This current submission also makes use of the reference period 2001-2015 and the construction of the national FREL/FRL in this submission is based on the average of the annual net GHG emissions during the reference period (historical emissions and trends). 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. This new approach is a step further on completeness and the use of the sample approach for all activity data compared to partial use of country data mixed with other proxies and global datasets as used in the 2017 submission.

Associated REDD+ Activity	Source Category
Deforestation	Forest Land Converted to Croplands
	Forest Land Converted to Grassland
	Forest Land Converted to Wetlands
	Forest Land Converted to Settlements
	Forest Land Converted to Other Land
Degradation	Forest Land Remaining Forest Land (Disturbed)
Enhancement of C Stocks	Land Converted to Forest Land, Forest Land Remaining Forest Land (Disturbed)

The FRL for this submission is **1,526,457 tCO_2-e** within the reference period (2001-2015) and is taken as the benchmark to assess the performance of the implementation of the three REDD+ activities selected: Reducing emissions from Deforestation, Reducing Emissions from Forest Degradation and Enhancement of Carbon Stocks at national level.

This assessment indicates that in the last 15 years, about **275,107 ha** of forest have been cleared and converted to other land use. This is 0.34% forest loss in 15 years. A total of 117,014 ha of Forest was disturbed (degraded) between 2001 and 2015.

The significant difference in emissions levels between the two reports is mainly attributed to the following:

In the first submission, Ghana had a challenge of disaggregating tree crops from forest which led to an overestimation of the Activity Data. However in this methodology, Ghana had access to high resolution data, and with the experience acquired by the technical experts, proper disaggregation could be done.

In this current submission, the Collect Earth tool allows interpreters to see the changes using a time scale, however for the previous methodology, Ghana adopted the use post-stratification approach (map subtraction) which passed on inherent errors.

1. BACKGROUND

In accordance with decision 12/CP.17, Ghana welcomes the opportunity to submit a revised Forest Reference Emission Level and Forest Reference Level (FREL/FRL) for consideration by the United Nations Framework Convention on Climate Change (UNFCCC). There are two main components to the revised FREL/FRL:

(a) Establishment of Ghana's historical emissions profile from the forestry sector
(b) The development of the revised FREL/FRL

This report presents an overview of the new methodologies and data adopted to estimate the historical emissions profile as well as details of how these baseline emissions were applied for developing the revised FRL.

1.1 Objectives of Revising the Forest Reference Level:

Ghana understands that Forest Reference Levels should be updated periodically as appropriate, taking into account new knowledge, new trends and / or new methodologies. Ghana therefore, intends to achieve the following national and international objectives with the submission of the revised FREL/FRL.

Nationally:

- To access the progress of REDD+ implementation in Ghana
- To access the forest sector contribution to the National Climate Change Mitigation Actions
- To seek consistency with other submissions (Nationally Determined Contributions, Biennial Update Report, National Greenhouse Gas Inventory) submitted by the country, and other future submissions which will be in line with the Paris Agreement.

Internationally:

- To access results-based payments for REDD+ Actions.
- To contribute to the achievement of the Paris Agreement

1.2 Development of FRL in the context of REDD+ Implementation in Ghana:

REDD+ as an international Climate Change mitigation framework under the UNFCCC offers financial incentives to developing countries who are able to reduce global carbon emissions from deforestation and forest degradation. Ghana recognizing the immense benefits of REDD+, adopted the mechanism a little over 10 years ago and have noted remarkable achievements including the development of the REDD+ Strategy in 2016. Subsequently in 2017, Ghana submitted a Forest Reference Level which has been reviewed for re-submission to the UNFCCC. The revision has been occasioned by the availability of a more rigorous methodology, which is reflective of Ghana's landscape.

Ghana has an estimated total land area of about 23 million ha. In the year 2000, forests are estimated to have covered 5.7 million hectares which has declined to 5.5 million ha with a historical deforestation of 0.33% (appx 17000 ha yr-1).

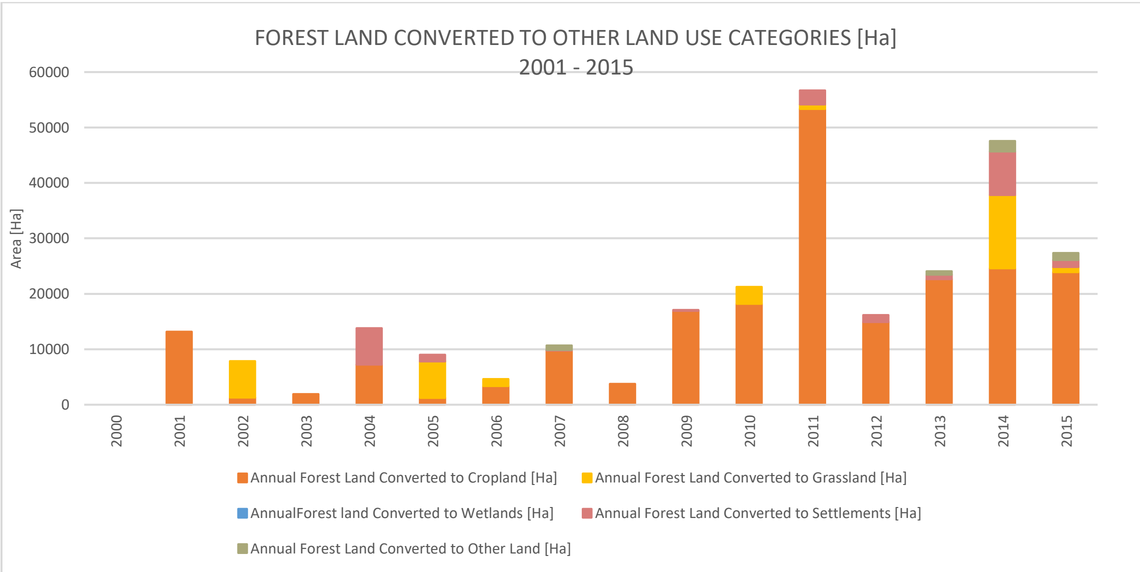
Ghana's total forest area is divided into three main ecological zones; the High Forest zone (HFZ), Transitional Zone (TZ) and the Savannah Zone (SZ). These zones have been delineated based on climatic factors, notably rainfall and temperature. The main ecological zones are subdivided into nine forest strata (as shown in Figure 13.)

Ghana's High Forest Zone (HFZ) falls within the biodiversity hotspot of the Guinean forests of West Africa, one of the 36 most important biodiversity areas in the world.[1] 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.

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 (Figure 1), which is estimated to be 0.33%, and forest degradation (Figure 2) 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.

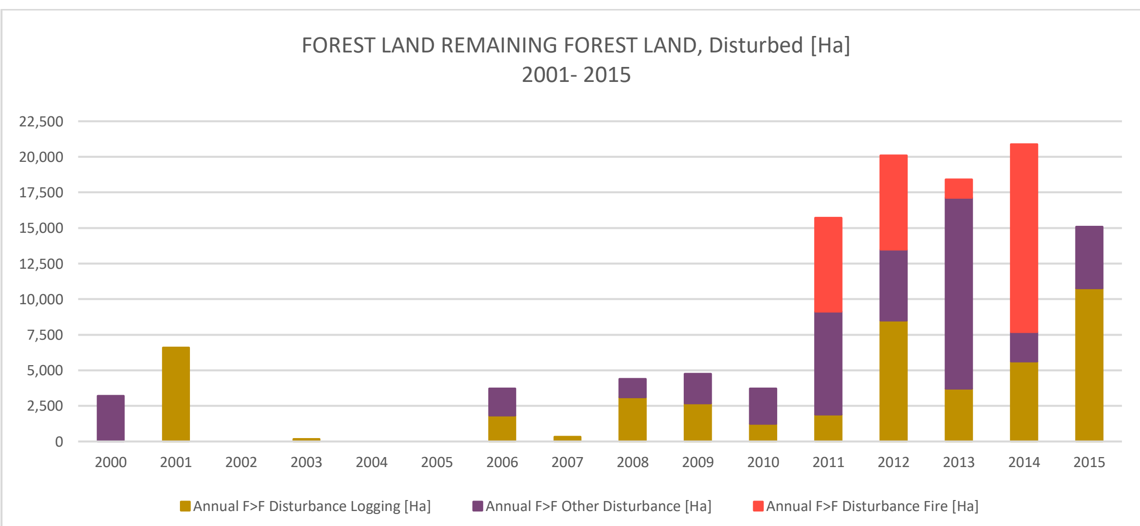
[1] Ghana Forestry Commission. 2015. Ghana National REDD+ Strategy. Available at: http://extwprlegs1.fao.org/docs/pdf/gha178876.pdf

Figure 1Forest land converted to other land use categories (deforestation) [Ha]



Source: Collect earth assessment by GFC.

Figure 2Disturbances in Forest land remaining Forest land (Degradation) [Ha]



Source: Collect earth assessment by GFC.

1.3 Application of UNFCCC Modalities to Ghana's Revised FRL

The construction of FREL/FRL as benchmark for assessing performance is 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[2]. A step-wise approach is allowed that enables Parties to improve the FREL/FRL by incorporating better data, improved methodologies and, where appropriate, additional pools. The FREL/FRL are expressed in units of tons of CO_2 equivalent (CO_2e) per year and must maintain consistency with the 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 1UNFCCC modalities relevant to Ghana's national FREL/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 FREL/FRL for the GCFRP and is submitting here a FREL/FRL at national level.
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. Soil organic carbon has not been included in this submission (to be considered in future submissions, if significant). Gases - CO_2 always accounted for emissions and removals - CH_4 and N_2O accounted for fires in Forest Land that cause deforestation and forest degradation. Non-CO_2 emissions converted into CO_2-e.
Decision 12/CP.17 Annex, paragraph (c)	Activities included	Reducing Emissions from Deforestation Reducing Emissions from Forest Degradation Enhancement of Forest Carbon Stocks
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[3]
Decision 12/CP.17 Annex	The information should be guided by the most recent IPCC guidance and guidelines.	FREL/FRL estimates were developed using the 2006 IPCC Guidelines and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[4]
Decision 12/CP. 17 II. Paragraph 9	To submit information and rationale on the	Forest degradation and deforestation pose a significant threat to Ghana for two main reasons. Forests provide

[2] Decision 4/CP.15, paragraph 7.

[3] 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.

[4] https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

	development of forest FRLs/FRELs, including details of national circumstances and on how the national circumstances were considered	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

Considering all these Decisions and Considerations of the process agreed under the Paris Agreement, Ghana has the honor to submit to the UNFCCC its Forest Reference Emissions Level (FREL) for Reducing Emissions from Deforestation and Reducing Emissions from Forest Degradation; and the Forest Reference Level (FRL) for the Enhancement of Forest Carbon Stocks, at national level, to undergo the technical assessment under the UNFCCC.

The country has made its best effort to present all its information in a transparent, accurate, complete, comparable and consistent manner following the basic principles for preparing greenhouse gas inventories of the 2006 Intergovernmental Panel on Climate Change (IPCC).

2. KEY ELEMENTS

2.1 Modalities for FREL/FRL according to 12/CP.17

- **Paragraph 7**. The FREL presented by Ghana is expressed in **tons of CO_2 equivalent per year (**t CO_2-e), to serve as a benchmark for assessing the country's performance in implementing the REDD+ activities.

- **Paragraph 8.** As explained below (section 1.3.), Ghana developed a **single database for the National GHG Inventory (NGHGI) and the FREL/FRL.** This aims to ensure full consistency in future submissions to the UNFCCC (e.g., NGHGI, Biennial Update Report). All calculations are explicit to maximize transparency.

- **Paragraph 9**. The national circumstances considered in this FREL/FRL submission are explained in section 5.

- **Paragraph 10**. In this submission, Ghana presents an improvement plan, which considers the gradual improvement of methods, as well as the future inclusion of additional carbon pools.

- **Paragraph 11**. Ghana's FREL/FRL is presented at the national level.

- **Annex, chapeau**. the information provided by Ghana is guided by the 2006 IPCC guidance and guidelines, specifically the **2006 IPCC Guidelines for National GHG Inventories but also the 2019 IPCC Refinement, as appropriate.**

- **Annex, paragraphs (a), (b)**. A comprehensive database is attached to this report. Also, extensive descriptions of the methods and data used are provided below to facilitate understanding by the readers and the UNFCCC technical assessment team. This database is also relevant to the results to be presented in the Biennial Update Report.

- **Annex, paragraph (c)**. Those carbon pools included and the reasons for the exclusion of a carbon pool in this submission are provided. In terms of activities covered, emissions and removals are considered for Forest land and conversions to and from Forest land, which cover any type of REDD+ activity. In essence, this is equivalent to including the selected REDD+ activities in the FREL/FRL as a benchmark for performance.

- **Annex paragraph (d)**. The forest definition used for the FREL/FRL is the same as that in the NGHGI.

3. REDD+ ACTIVITIES

As indicated in the Decision 1/CP.16, paragraph 71, Ghana has decided to develop a national forest reference emissions level (**FREL**) for the REDD+ activities "**Reducing Emissions from Deforestation**" and "**Reducing Emissions from Forest Degradation**" and a forest reference level (**FRL**) for the REDD+ activity "**Enhancement of Forest Carbon Stocks**", in accordance with national circumstances and as a benchmark to assess the country's performance in implementing three of the five activities referred to in decision 1/CP.16, paragraph 70: **reducing emissions from deforestation**, **reducing emissions from forest degradation**, **conservation of forest carbon stocks**, **sustainable management of forests** and **enhancement of forest carbon stocks**.

Definitions for the assessment of the AFOLU sector required defining key REDD+ terminologies within the Ghana national context. For the revision of the FREL/FRL, Ghana focused on Reducing Emissions from Deforestation, Reducing Emissions from Forest Degradation and Enhancement of Forest Carbon Stocks.

3.1 Deforestation

Deforestation occurs when Forest Land is converted to another land-use category as defined by the IPCC (Cropland, Grassland, Wetlands, Settlements or Other Land). For this report the focus is only on anthropogenic causes.

3.2 Forest degradation

Forest degradation is the process where a forest is disturbed but continues to remain as a forest. In the case of Ghana, this happens in the loss of forest quality that takes place within the forest definition of an area of a hectare, with minimum height of 5m and 15% canopy cover and above. Human disturbances are illegal logging, fire, shifting cultivation, infrastructure, and (livestock) grazing. For degraded forest, within the 0.5 hectares visually interpreted in the Collect Earth/Open Foris (CE/OF) tool, 16 % to 90 % of the canopy need to have remained after the human or natural disturbance.

3.3 Enhancement of forest carbon stock

The enhancement of forest carbon stock focuses on the creation or improvement of carbon pools and their capacity to store carbon. This submission considers enhancements of carbon stocks due to other land uses converted to Forest lands as well as due to restoration or recovery of Forest land remaining Forest land (disturbed).

Table 2 provides the relationship between the REDD+ activities selected in this submission and the land-use categories and sub-categories following IPCC structure.

Associated REDD+ Activity	Source Category
Deforestation	Forest Land Converted to Croplands
	Forest Land Converted to Grassland
	Forest Land Converted to Wetlands
	Forest Land Converted to Settlements
	Forest Land Converted to Other Land
Degradation	Forest Land Remaining Forest Land (Disturbed)
Enhancement of C Stocks	Land Converted to Forest Land, Forest Land Remaining Forest Land (Disturbed)

4. CONSISTENCY WITH THE NATIONAL GHG INVENTORY

Ghana submitted its last National Greenhouse Gas Inventory (NGHGI) to the UNFCCC on July 21st, 2020. For Forestry and Other Land Uses (FOLU), Ghana estimated GHG emissions and removals using the land-based approach in the 2006 IPCC Guidelines. To the extent possible, Ghana used country-specific data in its NGHGI.

The country-specific data used for estimating the net emissions from FOLU was obtained from the studies conducted under the Forest Preservation Programme (FPP) in 2012 and during the preparation of the national Forest Reference Emission Level (FREL) in 2017 by the Forestry Commission in Ghana. Whenever necessary, data from FAOSTAT were also used. To a large extent, the FREL was the main data source for the FOLU inventory.

For the NGHGI, the activity data identifying land remaining in a same land-use category and land converted to other land-use categories was based on the analysis of satellite images for the years 1990, 2000, 2010 and 2013 and 2015. The emission factors and parameters to estimate the net CO_2 emissions derived mainly from the work done by the Forestry Commission of Ghana under the Forest Preservation Programme (FPP).

In this submission, the activity data (AD) are generated from the analysis of Collect Earth sample plots and the emission factors and parameters derived partially from the FPP and partially from country-specific data in the scientific literature produced by Ghanaian researchers. IPCC default values were used when country-specific data were not available or was judged not to be accurate enough to be used in this FREL/FRL submission.

The results in this FREL/FRL submission will feed into the next submission of the National Greenhouse Gas Inventory (NGHGI) which is currently ongoing to be submitted by Ghana to the UNFCCC. This is to ensure full consistency between the FREL/FRL and the national inventory.

5. FOREST REFERENCE EMISSIONS LEVEL/FOREST REFERENCE LEVEL OF GHANA

5.1 Outline of the Forest Reference Emission Level and the Forest Reference Level (2001-2015)

This FREL/FRL submitted by Ghana corresponds to the net Greenhouse Gas (GHG) emissions and removals estimated using the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines (2006 IPCC GLs) and 2019 Refinement as a basis. The Gain-Loss method in the IPCC 2006 GLs is used to estimate the changes in carbon stock in forest lands remainig forest lands, and forest lands conversion to and from other land use categories, covering the entire country. The relevant forest-related estimates were calculated using a country-specific excel tool (REDD+ Foundation Platform)[5], provided in this submission. All land in the country is considered as managed land.

5.2 Carbon pools

The national FREL/FRL includes the following carbon pools: **above-ground biomass**, **below-ground biomass**, **dead organic matter** (litter and deadwood) and excludes **soil organic carbon**.

5.3 Greenhouse gases

The national FREL/FRL includes emissions of **carbon dioxide (CO_2), methane (CH_4)** and **nitrous oxide (N_2O)** from biomass burning in Forest Land and Forest Land conversion. Emissions in carbon dioxide equivalents (CO_2-e) are reported using the **100-year global warming potentials** (GWPs) contained in **IPCC's Second Assessment Report (AR 2)**.

5.4 Scale

The scale of the FREL/FRL is National. The total land area is about 23 million ha. The country is divided into 16 regions with 3 ecological zones. A stratified systematic sampling grid of 10,446 0.5-ha plots located across the entire country was used to allow a national coverage of Ghana's landscape.

5.5 Reference Period

The reference period for this FREL/FRL is 2001-2015. No adjustment is applied.

5.6 Definition of the FREL/FRL

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.

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[5] The REDD+ Foundational Platform is similar to the IPCC working sheets, but is adapted to capture specific country needs and circumstances

The average FREL/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 FREL/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 FREL/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.

The construction of the national FREL/FRL in this submission is based on the average of the annual net GHG emissions during the reference period (historical emissions and trends).

The FREL/FRL is therefore estimated as the average of the annual net GHG emissions from the period 2001-2015, as indicated in Table 3. The FREL/FRL is to be applied as a benchmark for net emission reductions in each year of the period 2016 to 2019. Figure 3 provides a representation of the historical net GHG emissions from 2001 – 2015 (in green); the average GHG net emissions from 2001-2015 (in blue) and the FREL/FRL defined in this submission (in red).

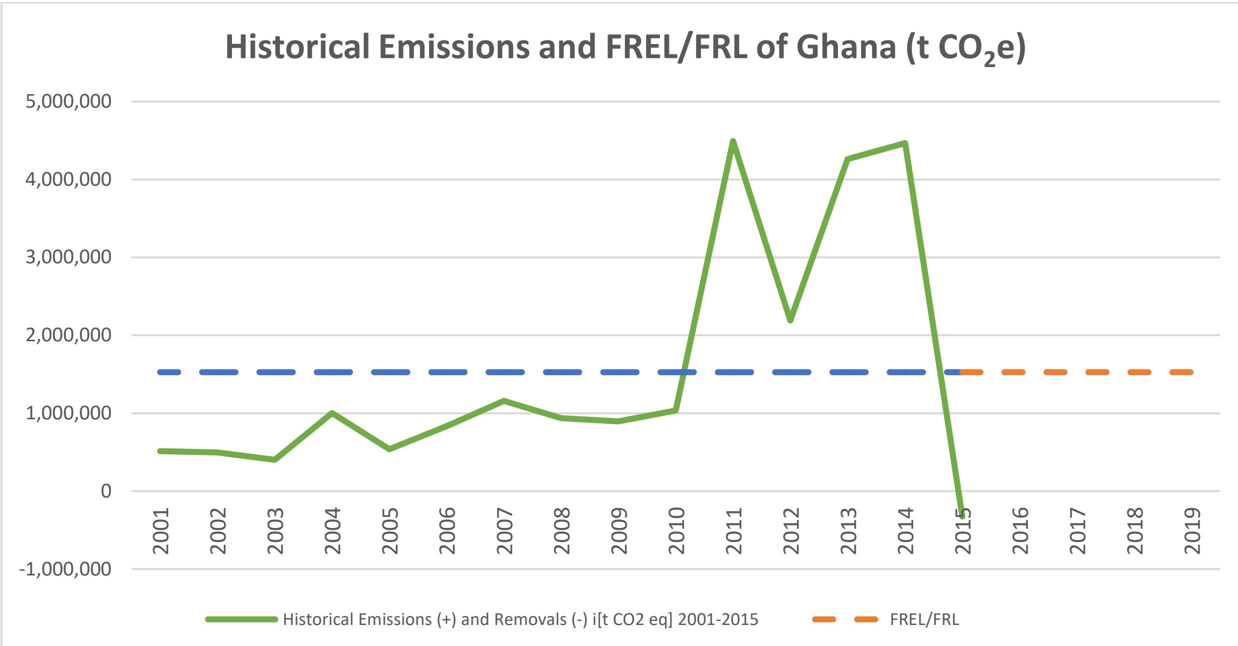
5.7 Period of application of the FREL/FRL

The FREL/FRL will be applied for years 2016, 2017, 2018, 2019 and 2020 onwards.

Table 3 Calculation of the FREL/FRL (net emissions) in tCO2e

	YEAR	T CO_2 EQ
HISTORICAL GHG EMISSIONS AND REMOVALS [CO2,CH4, N2O]	2001	514,607
	2002	496,225
	2003	402,158
	2004	1,002,496
	2005	537,097
	2006	832,314
	2007	1,157,793
	2008	937,674
	2009	895,469
	2010	1,036,431
	2011	4,492,680
	2012	2,189,523
	2013	4,259,994
	2014	4,468,776
	2015	-326,377
FREL/FRL (HISTORICAL AVERAGE OF GHG EMISSIONS (+) AND REMOVALS (-)) [CO2,CH4, N2O]	2016	1,526,457
	2017	1,526,457
	2018	1,526,457
	2019	1,526,457

Figure 3 Historical GHG Emissions and Removals, and FREL /FRL of Ghana



6. FOREST SECTOR BACKGROUND

Ghana is located between latitude 11.50N and 4.50S and longitude 3.50W and 1.30E. Ghana's climate, like in the rest of the Guinea Coast, is determined largely by the interplay of two air masses: a hot, dry continental air mass that forms over the Sahara; and a warm, humid maritime tropical air mass that forms over the South Atlantic. Both air masses move towards the Equator with their hemispheric winds and meet annually at the Guinea Coast for several months. Continental air moves southward with the northeast trade winds, known in western Africa as the harmattan, and maritime tropical air moves northward with the southwest trades. The zone where these air masses converge is characterized by seasonal line squall precipitation. The convergence zone itself oscillates north and south, following the seasonal movements of the overhead sun and the thermal equator; it reaches its most northerly position in the central Sahara, about latitude 21° N, in August, and its most southerly position about 7° N, a few miles north of the Ghana coastline, in January. Rains occur when the dominant air mass is maritime tropical, and drought prevails when continental air and the harmattan dominate.

Although soils and biotic factors (i.e., those pertaining to living organisms, including humans) are important, vegetation is primarily determined by precipitation. The country 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 on the basis of climatic factors, notably rainfall and temperature[6].

In the forest zone (the southern third of the country) and the area along the Akwapim-Togo Ranges, where the mean annual precipitation exceeds 45 inches [1,140 mm] and is well distributed throughout the year without a pronounced dry season, the predominant vegetation is evergreen and tropical semi-deciduous forest. There are tall trees of varying heights, forming a closed canopy at the top, above which tower a few forest giants, such as the silk cotton tree, the wawa tree (African whitewood, a hardwood), and the African mahogany. The evergreen forest is in the extreme southwest, where the precipitation exceeds 65 inches (1,650 mm) a year, while there is a semi-deciduous forest farther north.

The High-Forest Zone (HFZ) is limited to the southwest portion of the country and occupies a third of the land area and It is the region with the highest precipitation in the country, where rainfall may exceed 2000 mm in the wettest parts (Wet Evergreen Zone). The HFZ consists of both rainforest and deciduous forests and falls within the biodiversity hotspot of the Guinean forests of West Africa, one of the 36 most important biodiversity areas in the world.

The Transition Zone (TZ) occupies the mid-part of the country. It portrays characteristics of both the High Forest and Savannah Zones with semi-deciduous forest in the middle-belt, and with annual rainfall between 1,200 mm and 1,800 mm.

[6] Ghana REDD+ Strategy, 2016.

The Savannah Zone (SZ) occupies the northern part of the country and stretches further south into the east coast consisting of Coastal savannah, Guinea savannah and Sudan savannah, with annual rainfall between 760 mm and 1200 mm.

There are three principal types of vegetation from south to north occurring in the coastal savanna, in the forest zone, and in the northern savanna zone.

The coastal savanna in the southeastern plains around Accra consists of a mixture of shrub and tall grass (mostly Guinea grass), with giant anthills, often 10 to 14 feet (3 to 4 meters) high, providing an anchorage for thicket clumps that often include *Elaeophorbia* (a fleshy-leaved plant containing caustic latex) and other drought- and fire-resistant species such as the baobab (*Adansonia digitata*).

The northern savanna is found in the northern two-thirds of the country, where the low annual precipitation, between 30 and 45 inches (760 and 1,140 mm), occurs in a single season and is followed by a period of intense drought. There, the vegetation consists mostly of tall Guinea grass, together with a scattering of low trees, such as the shea butter tree, various species of acacia, and baobabs. Along the northern border the savanna gives way to a more open type of grassland that has developed largely as a result of prolonged human interference.

Ghana's forest lands are endowed with rich natural resources—gold, timber, non-timber forest products (NTFPs) etc. Ghana's forest resources continue to face pressure of deforestation and forest degradation with the principal drivers identified as unsustainable logging and fuelwood harvesting, agricultural expansion, free ranging pastoralists, permanent and shifting cultivation. It also includes traditional slash and burn practices, wildfires and urban infrastructure development, such as human settlements, roads, utilities, schools etc. The dense forest zone has been affected mainly by farming activities and timber exploitation. The country has a strong commitment to democratic governance, civic and traditional leadership. To ensure the sustainable use of the country's rapidly diminishing forest resources, the government has embarked on a forestry policy involving the compulsory reforestation of cutover areas and more-accurate measurements of exploitable timber and rates of extraction and regeneration, as well as a ban on the export of round logs.

6.1 National Policies, Legislation and Measures related to Forest sector

Ghana has a well-established range of laws and regulations which govern its forestry sector (refer to Table 4). The country has had an established history of laws governing the forest sector since 1906. There is currently a range of policy and regulations that impact the sector, and several government bodies that oversee its operation.

Table 4. National Policies, Legislation and Measures in Ghana.

Relevant National Policies, Strategies and Development Priorities	Overview
An Agenda for Transformation: The Coordinated Programme of Economic and Social Development Policies (2014-2020)	This Agenda outlines medium-term policy interventions for effective natural resource management, which covers the following: a. Biodiversity and protected area management; b. Land management and restoration of degraded forests; c. Wetlands and water resources management; d. Community participation in natural resources management; and e. Climate variability and change.
National Climate Change Policy (2012)	National Climate Change Policy (NCCP) 2012 has the vision of ensuring a climate resilient and climate compatible economy while achieving sustainable development through equitable low carbon economic growth.
National Climate Change Policy Action Programme for Implementation: 2015–2020	The purpose of the national climate change master plan is to put in place robust measures needed to address the challenges posed by climate change and climate vulnerability. Policy Focus Area 4 seeks to design and implement interventions that increase carbon sinks.
The Revised Forest and Wildlife Policy (2012)	This is the parent sector policy aimed at the conservation and sustainable development of forest and wildlife resources in Ghana.
The National Land Policy (1999) with the associated Land Administration Project (Phase II)	The policy outlines specific actions that are consistent with the Mission and Vision of the Forestry Commission and the goals of REDD+. Under security of tenure and protection of land rights, it clearly states that decision making with respect to disposal of land should take into consideration: • The natural resources of the land; • Conservation of land for future generations; • Protection of land rights of the present generation; and • Accountability to the subjects for whom the land is held in trust.
National Environment Policy 2014	The National Environment Policy commits to the principle of optimum sustainable exploitation of the ecosystem resources. The policy recognizes serious environmental challenges including loss of biodiversity, land degradation, deforestation and desertification, wildfires, illegal mining, air and water pollution facing Ghana.
Low Carbon Development Strategy (2016)	The overall objective of this strategy is to contribute to global climate change mitigation through the development of an economically efficient and comprehensive Low Carbon Development Strategy (LCDS) for Ghana together with a monitoring reporting and verification system and an action plan.
Forest Law Enforcement, Governance and Trade (FLEGT)	Forest Law Enforcement, Governance and Trade (FLEGT) Initiative (as part of the Voluntary Partnership Agreement (VPA)), and the projects under Ghana's FIP all provide a strong set of complementary channels for addressing the major drivers of deforestation and degradation in Ghana, and for moving forward in a performance-based and climate-smart manner.

The National Tree Crops Policy	The policy states the vision as "a competitive and sustainable tree crops sub-sector, with focus on value chain development and improved technologies to create job opportunities, ensure food security, enhance the environment and improve livelihoods."
Ghana Cocoa Sector Development Strategy (CSDS) II, 2015	The focus of the CSDS II is on sustainability through economic empowerment of smallholder cocoa farmers. The vision is to create a modernized, resilient and competitive cocoa environment where all stakeholders strive toward a sustainable cocoa economy in which farmers and their communities can thrive.
National Climate Smart Agriculture and Food Security Action Plan (2016-2020)	The Action Plan is an effort to translate to the ground level the broad national goals and objectives in climate-smart agriculture.
National Riparian Buffer Zone Policy 2011	The Ghana Riparian Buffer Zone Policy aims at ensuring that all designated buffer zones along rivers, streams, lakes, and reservoir and other water bodies shall be sustainably managed for all.
Ghana National Bioenergy Policy 2010 - Draft	The Bioenergy policy paper addresses the policy issues and recommendations for achieving the overall objectives of the Government in ensuring sustainability of the bioenergy sector.
Ghana Strategic Investment Framework (GSIF) for Sustainable Land Management (SLM) (2009 – 2015)	The goal of the GSIF was to "support the country's priorities in improving natural resource-based livelihoods by reducing land degradation, in line with the Millennium Development Goals 1 (Extreme Poverty and Hunger) and 7 (Extreme Environmental Sustainability).
Sustainable Development Goal 2015	The Sustainable Development Goals are a set of global development goals adopted to end poverty, protect the planet and ensure prosperity for all. Each goal has specific targets to be achieved over the next 15 years (2016-2030).
Ghana REDD+ Strategy (GRS)	The GRS seeks to significantly reduce emissions from deforestation and forest degradation over the next twenty years, whilst at the same time addressing threats that undermine ecosystem services and environmental integrity so as to maximize the co-benefits of the forests.

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7. PROCEDURES AND ARRANGEMENTS FOR THE PREPARATION OF THE FREL/FRL

A brief description of procedures and arrangements undertaken to collect and archive data for the preparation of the FREL/FRL is included in Table 5, with information on the role of the institutions involved.

7.1 Schedule of FREL/FRL tasks

The process started with the review of reports and datasets, data collection, selection, processing and analysis, QC/QA procedures, and finalized with the definition of the activities included in this FREL/FRL submission. The process was completed by internal and external independent reviews.

Table 5 Major FREL/FRL stages and corresponding responsibilities.

Stages	Responsible
Identification and formation of the team	Ghana Forestry Commission (GFC)
Allocation of tasks	GFC
Technical training	Food and Agriculture Organization(FAO) of the United Nations, Coalition for Rainforest Nations(CfRN)
Data collection	FAO, GFC
QC/QA procedures	FAO, GFC, CfRN
Data analysis	GFC, CfRN
Compilation of the FREL	GFC
QC/QA procedures	CfRN

7.2 Means of data acquisition and management

Data acquisition

- **Activity Data:**
  Sample plot data was collected by experienced remote sensing experts with knowledge of the ground situation. The experts used Collect Earth for the sample plot data collection. Information on vegetation zone was not collected during the analysis of the samples but was directly extracted using the location of the sample unit and the corresponding vegetation zone from the vegetation zone map. A team of approximately 23 national experts combined to form the team of interpreters, mostly from the Forestry Commission, and other institutions such as the Forest Research Institute of Ghana, Centre for

Remote Sensing and Geographical information Service, CSIR-Soil Research Institute, Ministry of Food and Agriculture and Environmental Protection Agency (refer to Table 6).

Note 1: For the visual interpretation in the CE/OF tool, within the 0.5-hectare sample plot, deforestation required that less than 30% of the forest canopy remained after the human or natural intervention.

Note 2: In Collect Earth/Open Foris, the predominant sustainable forest practice was sustainable logging and its associated activities such as enrichment planting /plantation within degraded forest.

Note 3: In Collect Earth/Open Foris, shapefiles of the Forest Reserves and National Boundaries were superimposed on distributed samples to clearly distinguish between on and off forest reserves. This helped to allocate the level of intensification of samples that needed to be in forest reserves.

- Emission Factors:

  Country information/data were provided by the Forestry Commission of Ghana, including field plot data (above - and below-ground biomass, dead wood, litter and soil organic carbon) from the FPP project, to be described later in this document. In addition, some emission factors were estimated from country-specific scientific publications, where appropriate. In few cases the default values from the 2006 IPCC Guidelines and the 2019 IPCC Refinement to the 2006 IPCC Guidelines (2019 Refinement) were used.

Table 6. List of data providers, contact information (name and email) and roles.

Institution	Name	E-mail	Role
Forestry Commission	Kofi Affum-Baffoe	kab64baf@gmail.com	Sample interpretation and provision of data
Forestry Commission	Yakubu Mohammed	myakubu89@hotmail.com	Sample interpretation and provision of data
Forest Research Institute of Ghana	Ernest Foli	efoli@hotmail.com	Sample interpretation and provision of data
Forestry Commission	Prince Boama	boamaprince@gmail.com	Sample interpretation and provision of data
Forestry Commission	Jacob Amoako	jacobamoako2012@gmail.com	Sample interpretation and provision of data
Forestry Commission	Frank Kwadwo Owusu	Frankkwadwoowusu@gmail.com	Sample interpretation and provision of data
Forestry Commission	Tessia Boateng	tessiaboat@gmail.com	Sample interpretation and provision of data
Forestry Commission	Ebenezer Kwanin	ekwanin@gmail.com	Sample interpretation and provision of data
Forestry Commission	William 0sei-Wusu	williamkay88@gmail.com	Sample interpretation and provision of data
Forestry Commission	Ihejirika Christopher	chinihe@yahoo.com	Sample interpretation and provision of data
Forestry Commission	Raymond Sakyi	rksakyi@yahoo.com	Sample interpretation and provision of data
Centre for Remote Sensing and Geographic Information Services	Yusif Sitobu Abdullai	sitobuyusif14@gmail.com	Sample interpretation
Centre for Remote Sensing and Geographic Information Services	Foster Mensah	fkmawusi@gmail.com	Sample interpretation
CSIR-Soil Research institute - Accra	Justice Ankomah-Baffoe	ankoba.just@gmail.com	Sample interpretation and provision of data
Ministry of Food and Agriculture	Richmond Konadu Amoah	Sarfoabredu3@gmail.com	Sample interpretation and provision of data
Forestry Commission	Emmanuel Donkor	emmanueldonkor484@gmail.com	Sample interpretation and provision of data
Forestry Commission	Kofi Boateng Agyenim	bkofi646@gmail.com	Sample interpretation and provision of data
Forestry Commission	Agyemang Afua Birago	nanaagyemangworship@gmail.com	Sample interpretation
Environmental Protection Agency	Nutefe Kwesi Dra	kwnutefe@gmail.com	Sample interpretation
Ministry of Food and Agriculture	Nathanael Nii-Odai Laryea	niiodailaryea@gmail.com	Sample interpretation
Ministry of Food and Agriculture	Senyo Yao Gakpo	senyogakpo@gmail.com	Sample interpretation
Environmental Protection Agency	Mawuli Kwaku Gbekor	mgbekor@gmail.com	Sample interpretation
Forestry Commission	Lawrence Akpalu	lakpalu@gmail.com	Sample interpretation

7.3 Data management

All the relevant datasets used during the analysis have been documented. The archive database contains: (a) all input datasets and datasheets; (b) country-specific excel calculation tool, including GHG emission and removals estimates; (c) manuals and protocols; (d) literature reviewed; (e) completed QA/QC templates and protocols; and (f) all reports and documentation. Archives are held by the Ghana Forestry Commission.

8. METHODOLOGIES FOR ESTIMATING HISTORICAL GHG EMISSIONS AND REMOVALS

This section includes information on the methods, activity data and emission factors used in the construction of the FREL/FRL.

Table 7 summarizes the tiers associated to the activity data and emission factors used in the construction of the FREL/FRL, for each land-use category.

Table 6 Methods for Activity Data and Emission Factors used in the construction of the FREL/FRL

Category	CO_2		N_2O		CH_4	
	Activity Data	Emission Factors	Activity Data	Emission Factors	Activity Data	Emission Factors
5. LULUCF						
Forest Lands	CS	T1, T2, T3	CS	T1	CS	T1
Croplands	CS	T1, T2	NE	NE	NE	NE
Grasslands	CS	T2	NE	NE	NE	NE
Wetlands	CS	T1	NE	NE	NE	NE
Settlements	CS	T1	NE	NE	NE	NE
Other lands	CS	T1	NE	NE	NE	NE

T1 – Tier 1; T2 – Tier 2; T3 –Tier 3; CS – Country specific; D – IPCC default; NE – Not Estimated

8.1 Activity Data for land use and land-use change

Activity Data (AD) was obtained from the assessment of land use and land-use change based on a sampling approach (IPCC approach 3) using Collect Earth. The land-use and associated condition was determined for each year of the reference period (2000 – 2015). Forest Land was stratified by vegetation zones (Wet Evergreen, Moist Evergreen, Moist Semi-deciduous (north-west subtype), Moist Semi-Deciduous (south-east subtype), Upland Evergreen, Dry Semi-Deciduous - inner and fire zones, Savannah, Southern Marginal). Croplands were classified as annual or perennial crops and fallows. Grasslands, Wetlands, Settlements and Other Lands do not have further sub-classification.

The information on wood removals was derived from the Collect Earth assessment as cover loss instead of volume loss, as the tool does not provide that estimation. Losses due to disturbances were also identified, including fires, logging and shifting cultivation, specifically on Forest Land.

Figure 4 provides examples of disturbance events (logging, fire and others – e.g., mining) assessed in satellite imagery in the Collect Earth tool

Figure 4 Identification in satellite imagery of some disturbance events in the country

Logging – Moist Evergreen (left) and Most Semideciduous (right)

Fire disturbance – Savannah

Other disturbances – Moist Evergreen (left) and Moist Semi-deciduous (right)

8.2 Land Representation

Ghana implemented the 2006 IPCC GLs Approach 3 for land representation, characterized by spatially explicit observations of land-use categories and land-use changes, tracking patterns at specific point locations.

To implement Approach 3, Ghana used an image visualization tool called Collect Earth/Open Foris developed since 2013 as a tool for the collection of Land Use and Land-Use Change data using mid- and high-resolution satellite imagery. Collect Earth (as well as all the tools developed within Open Foris) can be downloaded for free from the OpenForis.org page (http://www.openforis.org/).

Collect Earth is a user-friendly, Java-based tool that draws upon a selection of other software to facilitate data collection. Collect Earth uses a Google Earth interface in conjunction with an HTML-based data entry form. Forms can be customized to suite country-specific classification schemes in a manner consistent with guidelines of the Intergovernmental Panel on Climate Change (IPCC).

Collect Earth facilitates the interpretation of high and medium spatial resolution imagery in Google Earth, Bing Maps and Google Earth Engine. Google Earth's virtual globe is largely comprised of 30-meter spatial resolution Landsat images, 2.5m SPOT imagery and high-resolution imagery from several other providers (CNES, Digital Global, EarthSat, First Base Solutions, GeoEye-1, GlobeXplorer, IKONOS, Pictometry International, Spot Image, Aerometrex and Sinclair Knight Merz). Collect Earth synchronizes the view of each sampling point across all three platforms. The tool enables users to enter data of current land use and historical land-use changes. Users can determine the period most appropriate for their land-use assessment objectives.

8.3 National grid

Ghana made a careful revision of its available data, inventory data and available maps to generate an improved change map that was instrumental for an effective sample distribution across the country.

The country used 4 different sampling designs with the support of the Collect Earth tool, namely: 8x8 systematic grid for national coverage (refer to Figure 5 and Figure 6), 4x4 km grid over the area covered by the Ghana Cocoa Forest REDD+ Program (GCFRP) and off reserve areas (refer to Figure 7), 2x2 km grid in the High Forest Zone and 1x1 km grid in forest reserves (refer to Figure 8). The rationale behind this was that Ghana's landscape is heterogeneous and many changes could be better captured in the 2x2 and 1x1 km grid intensification as opposed to the 4x4 km grid. For this reason, the 2x2 focused on the forest reserve areas while the 4x4 was off reserve areas.

Figure 5 Ghana Collect Earth National Sampling Grid

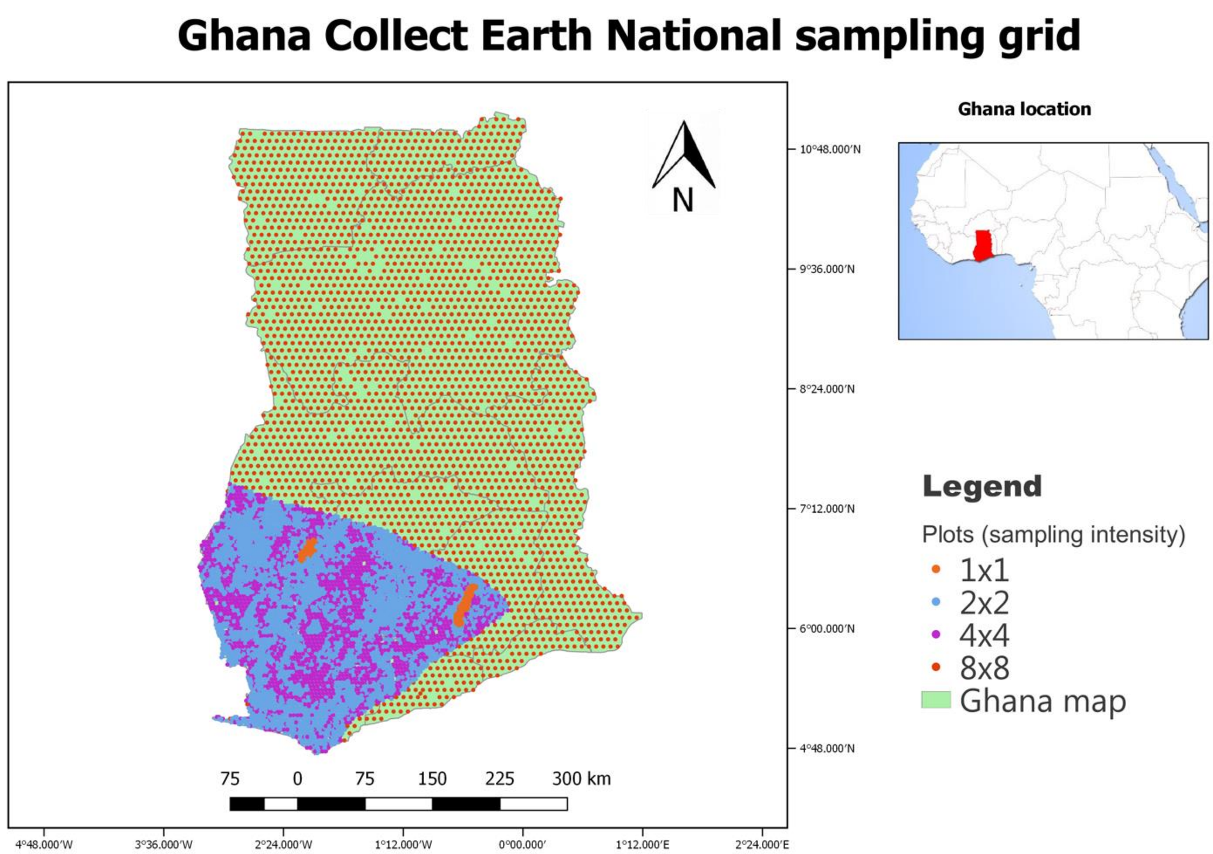


Figure 6 Different Sample Intensification Size

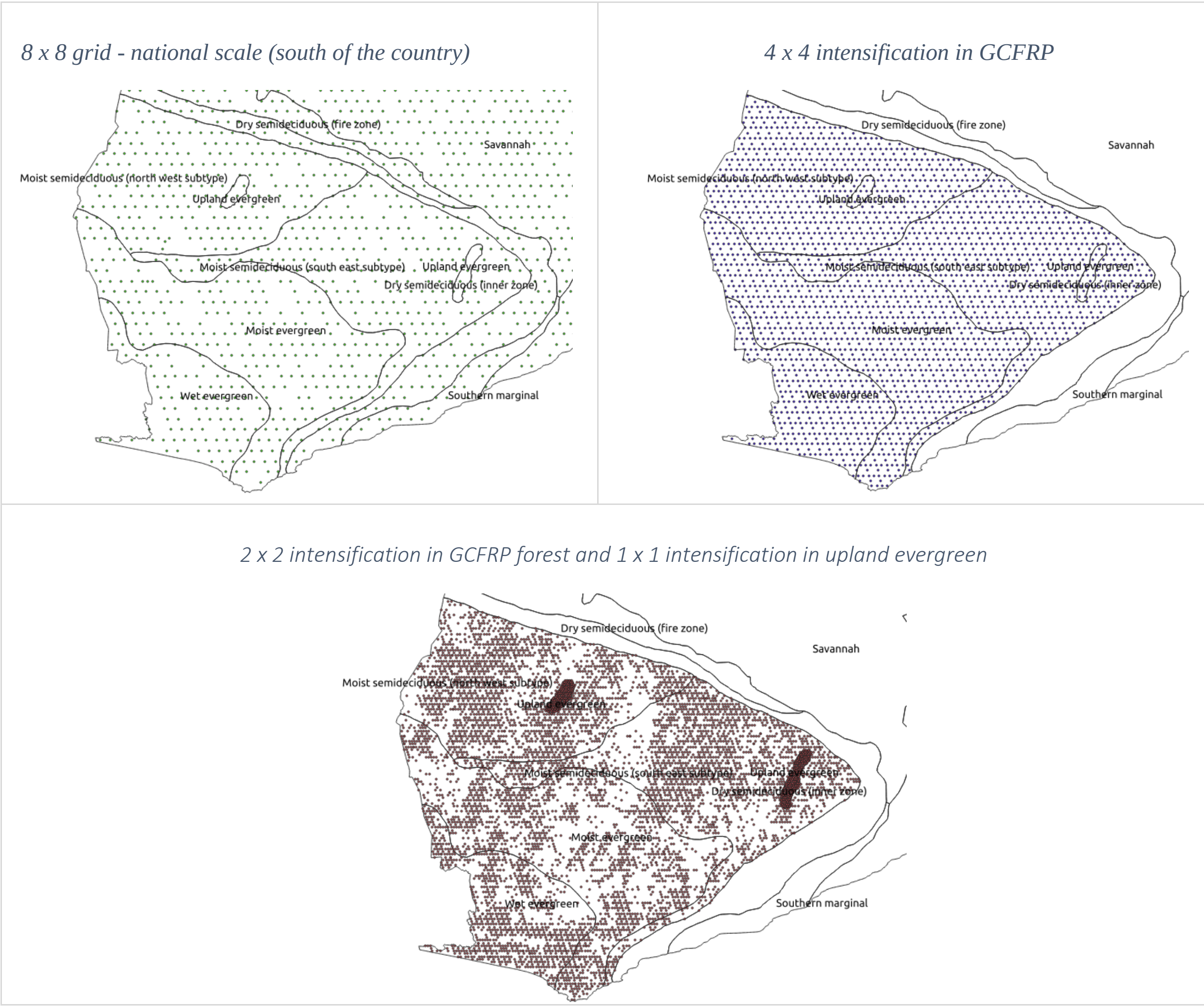


Figure 7 Plot size and distance among plots in Collect Earth

Plot Size: 0.5 Ha

Example distance among plots: 8 Km by 8 Km

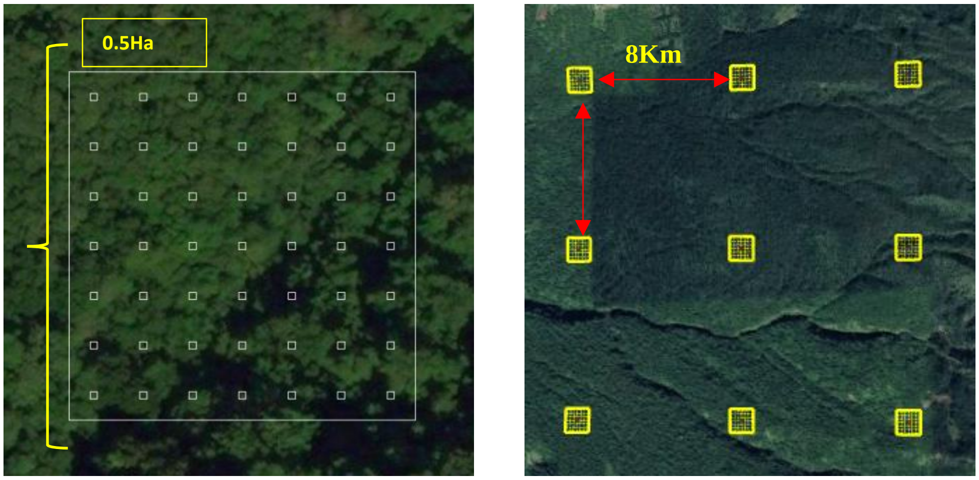
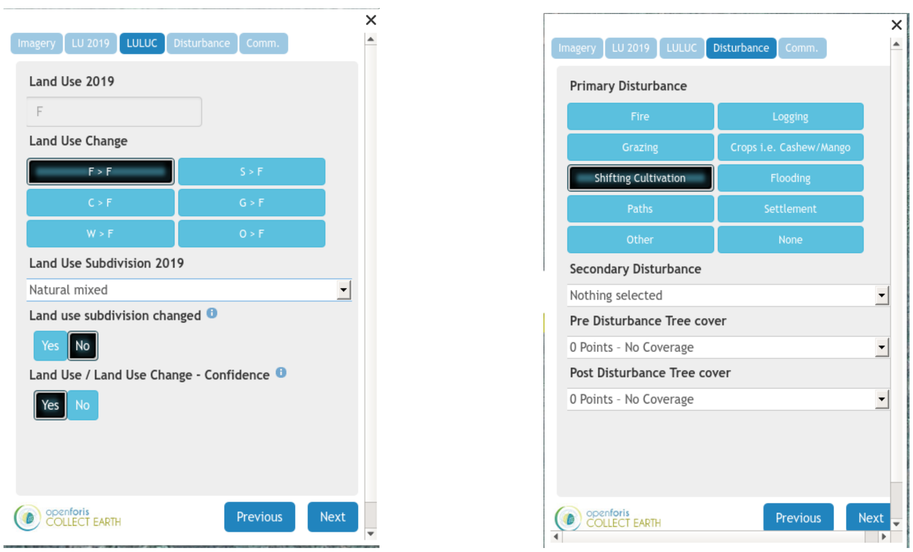


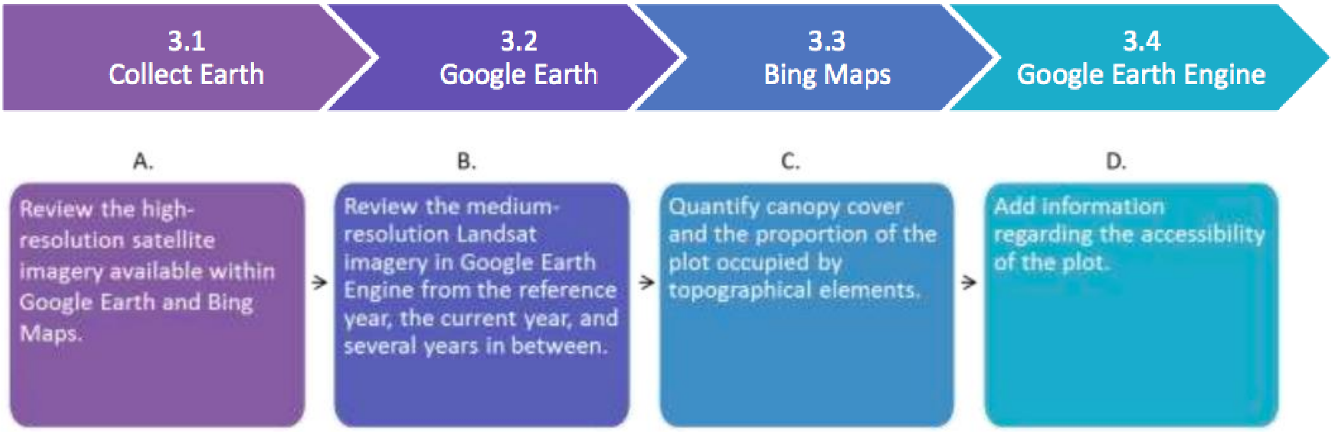
Figure 8 Collect Earth Survey



Plot analysis with support images (Sentinel, Landsat 8, Landsat 7, Vegetation Indices)

The following diagram indicates the steps for assessing land use with Collect Earth and its supporting software:

Google Earth, Bing Maps and Google Earth Engine (refer to Figure 11 and Figure 12). The diagram below provides an overview of the key steps:

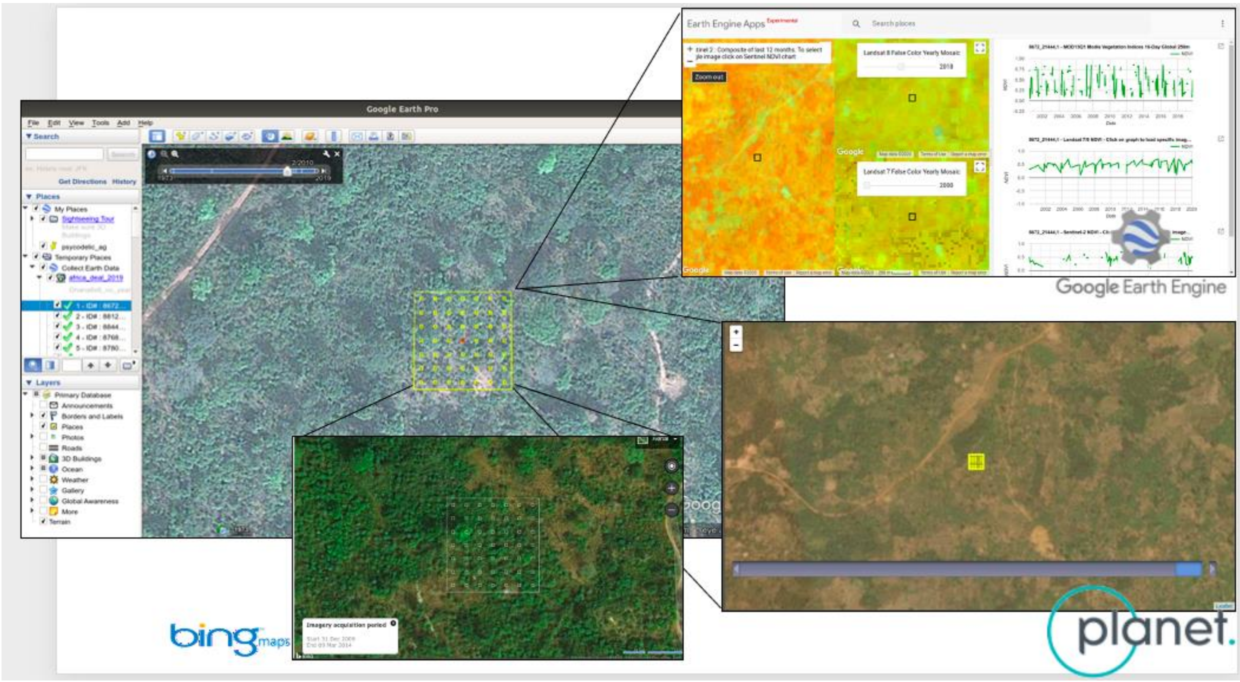


Microsoft's Bing Maps presents imagery provided by Digital Globe ranging from 3m to 30cm spatial resolution. Google Earth Engine's web-based platform facilitates access to the United States Geological Survey 30m resolution Landsat imagery. Through Bing Map, high spatial resolution satellite imagery from Digital Globe can be viewed and used for land-use assessments. Collect Earth plot locations have been linked with Bing Maps because the latter web mapping service has a slightly different geographic coverage. Through Google Earth Engine is the Landsat Greenest-Pixel top of atmosphere (TOA) reflectance composite. These composites, which are available for Landsat 4, 5, 7 and 8, are created by drawing upon all images of a site for a full calendar year. The greenest pixels, with the highest NDVI (normalized difference vegetation index) value, are compiled to create a new image. These composites are particularly useful in tropical forest areas that may be prone to frequent cloud cover. This infrared color composite presents forest with a reddish-brown color and agriculture, grass and shrubs in lighter shades of orange. Water appears purple and urban areas are shades of blue and green. This composite allows to extract information from bands that are sensitive to different types of reflectance.

The vegetation indices are indicators that describe the greenness — the relative density and health of vegetation — for each picture element, or pixel, in a satellite image. Collect Earth displays through Google Earth Engine Playground a set of time-frame charts with different vegetation indices to help the user identify possible trends and seasonality for the area of interest.

Figure 9 Historical Imagery

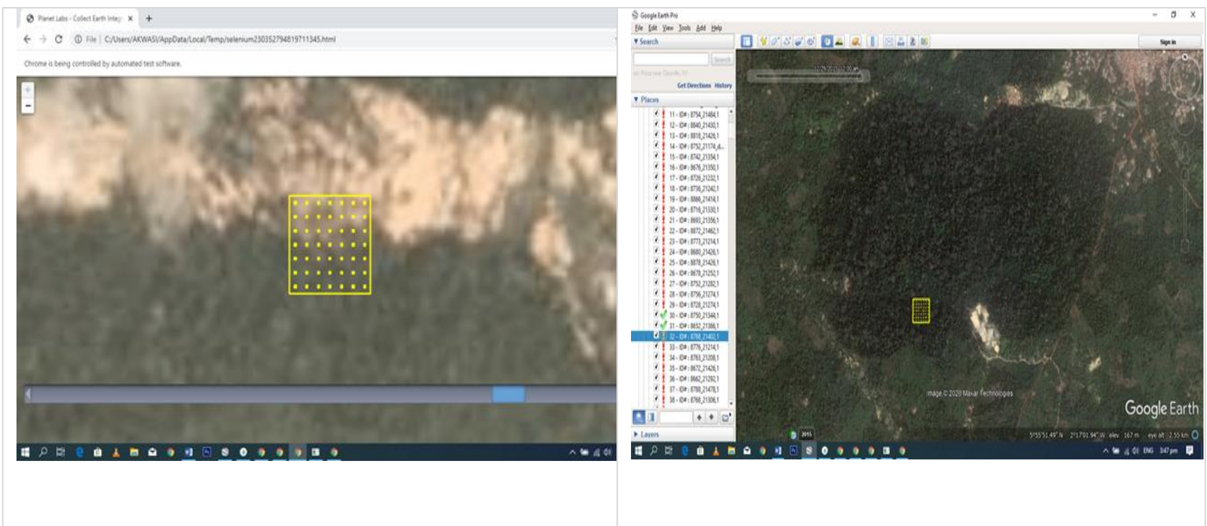
Figure 10 Example of Collect Earth integrated with Bing Maps, Planet & Google Earth Engine.



The differentiation of canopy cover density through visual interpretation is intrinsically related to the understanding of the national forest definition. Starting from the premise that plots of 0.5 ha undergo visual analysis through a visualization system (Google Earth) that focus on the changes in land use. This is part of a hierarchy level presented below, based on the interpretation of the plots for its category definition observed on satellite images.

Some examples of Collect Earth samples in different types of satellite imagery are in Figure 11 below:

Figure 11 Collect Earth Samples in different Satellite images



8.4 The response design

The response design refers to the rules applied when interpreting a sample plot, i.e. the labelling protocols.

Ghana adopted the IPCC hierarchy classification as a benchmark during the interpretation of the sampled plots, as follows:

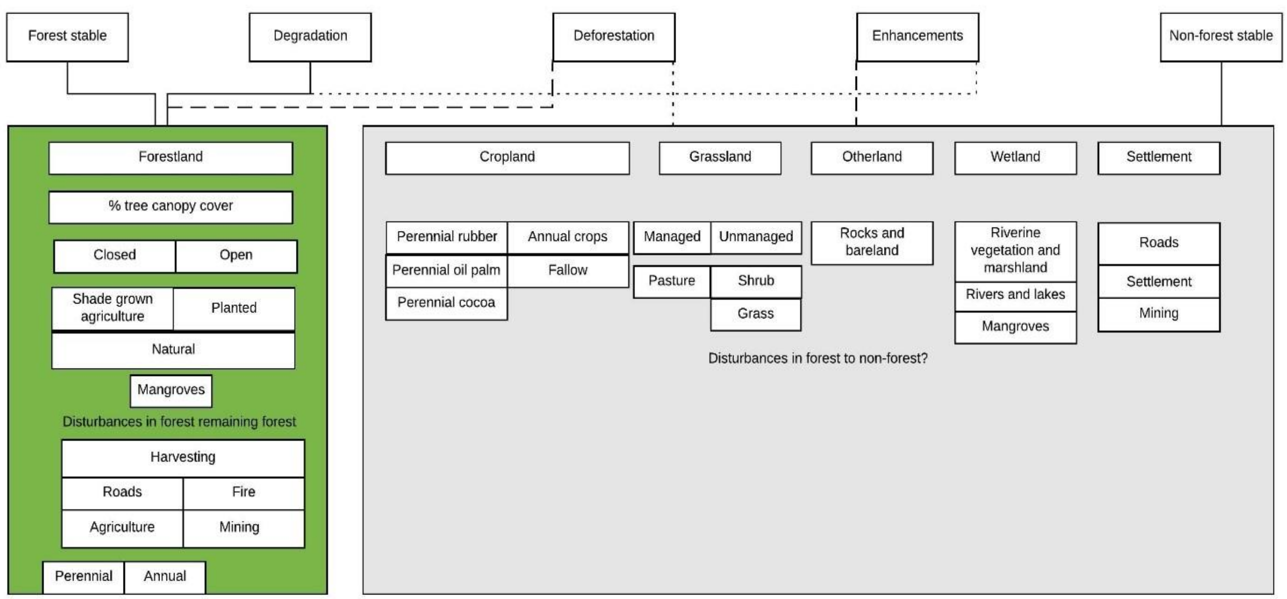
- Settlement = 20%
- Cropland = 20%
- Forest = 20%
- Grassland = 20%
- Wetland = 20%

- Other land = 20%

This is to infer that all sampled plots had at least 20% a land-use category that preceded over the other at any point in time following the order in which the land uses are, as listed above. E.g., if any plot had 20% settlement cover within a forest cover, it was labeled as "settlement". Inside each plot there is a 7 x 7 grid with 49 control points that help estimate the percent coverages within the plot. The control points are used as a guide to provide a precise interpretation consistent with the classification hierarchy.

As a result, following the 2006 IPCC Guidelines structure for the AFOLU sector, the land classification for Ghana includes the six main land-use categories: Forest land, Cropland, Grassland, Wetlands, Settlements and Other Land (Level 1). Additional subdivisions were defined following national circumstances, including climate zone, soil type and disturbance history, in line with IPCC guidance (Levels 2 and 3) (refer to Figure 12).

Figure 12. Collect Earth survey structure by IPCC Land Use categories



8.5 Land use classification

Table 8 provides the land classification in Ghana based on the six land-use categories at level 1 and sub-classifications. Further details on each of the levels is provided in sequence to the table.

Table 7 Land classification in Ghana following the 6 land-use categories defined in the 2006 IPCC Guidelines.

Forest definition			Closed forest has =>60% canopy, 1 ha and minimum height of 5m	Open forest has 15% < CC < 59% canopy cover (CC), 1 ha and minimum height of 5m	
IPCC categories Level 1	Symbol	Condition	Level 2	Code	Level 3
Forest Land	F	Undisturbed Forest	Moist semideciduous (north west subtype)	MSEMNW	Natural Evergreen
					Natural Deciduous
					Natural Mixed
					Broadleaf Deciduous
					Broadleaf Evergreen
					Broadleaf Mixed
					Plantations
					Riverine
					Shaded_ag
			Moist semideciduous (south east subtype)	MSEMSE	Natural Evergreen
					Natural Deciduous
					Natural Mixed
					Broadleaf Deciduous
					Broadleaf Evergreen
					Riverine
					Plantations
					Shaded_ag
			Moist evergreen	MEVER	Natural Evergreen
					Natural Deciduous
					Natural Mixed
					Broadleaf Deciduous
					Broadleaf Evergreen
					Riverine
					Plantations
					Shaded_ag
			Wet evergreen	WETEVER	Natural Evergreen
					Natural Deciduous
					Natural Mixed
					Plantations
					Riverine
					Shaded_ag
			Upland evergreen	UPEVER	Natural Evergreen
					Natural Deciduous
					Natural Mixed
					Broadleaf Mixed

					Riverine
					Shaded_ag
			Dry Semideciduous (Inner and Fire Zone)	DRYINNER	Broadleaf Deciduous
					Broadleaf Evergreen
					Natural Evergreen
					Natural Deciduous
					Riverine
					Shaded_ag
				DRYFIRE	Broadleaf Deciduous
					Broadleaf Evergreen
					Natural Evergreen
					Natural Deciduous
					Natural Mixed
					Riparian
					Mangrove
			Savanah	SAV	Broadleaf Deciduous
					Broadleaf Evergreen
					Broadleaf Mixed
					Natural Evergreen
					Natural Deciduous
					Natural Mixed
					Riverine
					Plantations
			Southern Marginal	SOUTH	Natural Evergreen
					Natural Deciduous
					Broadleaf Deciduous
		Disturbed	Fire Disturbance	FIRE	As a result of slash and burn agriculture, rampant bushfires
			Logging Disturbance	LOGGING	Timber harvesting and illegal chanin saw activities. Rosewood harvesting
			Other Disturbances (Shifting cultivation, grazing, other human impact)	DIST	Surface mining(legal and illegal), farming, Farming in forest reserves
Cropland	C		Perennial Crop	CPER	Rubber, palm and coconut, Cocoa, Permanent Crops
			Annual Crop	CANN	Rice, temporary crops
			Fallow	CFA	Fallows

Grassland	G		Grasslands	GRASS	Grasslands, grasslands with trees, grasslands with shrubs and shrublands
Wetlands	W		Flooded Lands	WET	Seasonal and permanent lakes and rivers, artificial water bodies
Settlements	S		Urban Areas	SET	City, town, village, infrastructure
Other Land	O		Other Land	OTHER	Barren soil, rocks, sand dunes
			Mining		Mining

Source: Collect earth assessment by GFC

Level 1: FOREST LAND (F)

Land covered by natural and planted forests. Includes all land with woody vegetation consistent with the thresholds in the forest definition adopted by the country. It also includes systems with a vegetation structure that fails to meet the forest definition but that *in situ* may reach the thresholds that characterize forest in the country. It excludes agricultural trees such as rubber, cocoa, oil palm, fruit and nut trees. Cocoa grown in an agroforestry landscape, with forest trees that meet the minimum forest thresholds are considered forests. Based on the survey from Collect Earth, forests are identified in areas as small as 0.5 hectare, with tree canopy cover greater than 15% and where the presence of cropland or settlement is less than 20%.

Forest Land in Ghana is classified as Open or Closed forests depending on the density of the canopy cover.

- **Open Forest -** This is modified or disturbed natural forest which has 15 - 59% canopy cover (FPP, 2010)[7]. Open forests may also have a three vertical layer structure: an upper layer made up of isolated mature trees; a middle layer made up of saplings and shrubs; and a ground layer dominated by grasses. In most instances, the middle and ground layers are merged, resulting in the dominant layer in the open forest. Open canopy forests exist mainly outside the gazetted forest reserves.

- **Closed Forest** - 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.

Level 2: This level refers to the nine ecological (or vegetation) zones in the country

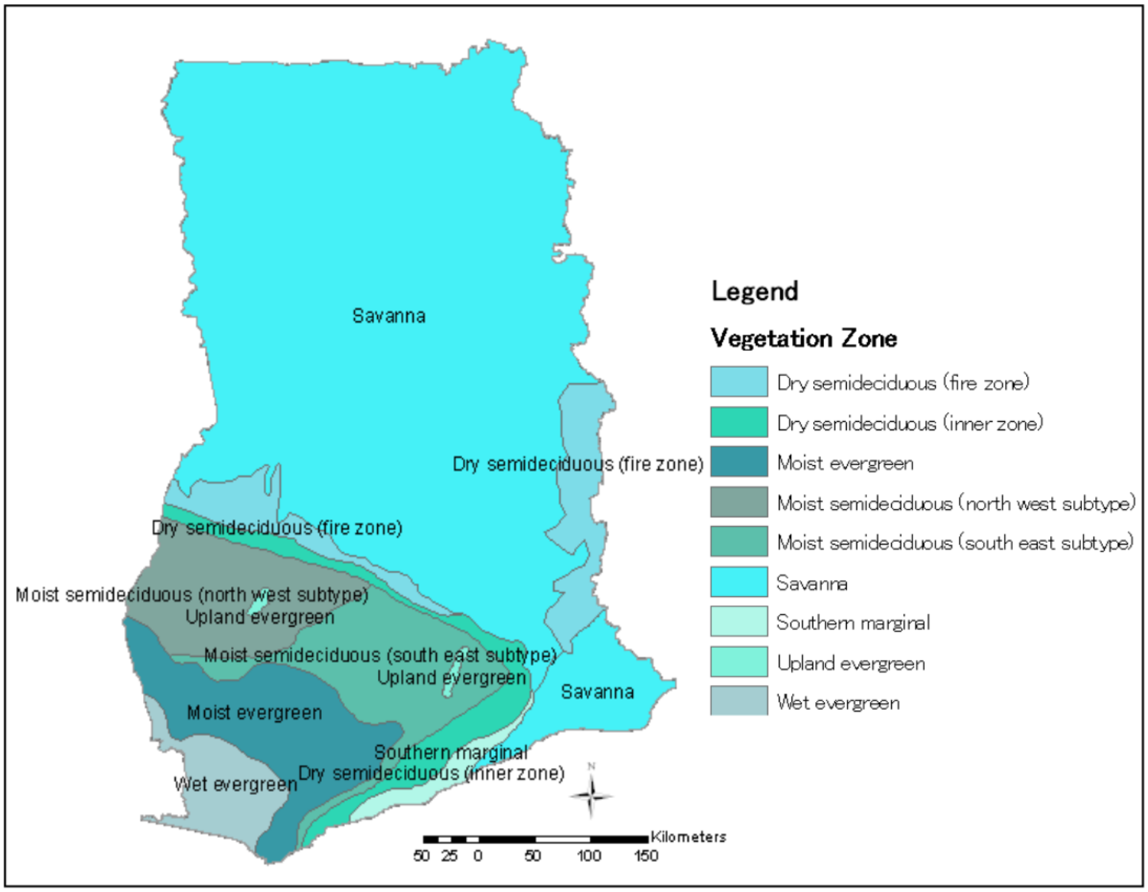
  - **Wet Evergreen -** This is forest that remains green throughout the year and does not shed leaves. Upper canopy trees rarely exceed 40m high. This stratum is very rich in species diversity and annual rainfall exceeds 1750mm. The soil PH is 3.8-4.3.

[7] Forest Preservation Programme.

- Moist Evergreen - This is forest that remains green throughout the year and does not shed leaves. Tree upper canopy trees grows up to 43m high. This stratum is very rich in species diversity and annual rainfall ranges from s 1500-1750mm. The soil PH is 3.8-4.3.
- Moist Semideciduous SE - A mixture of evergreen and deciduous species. It is the most productive among the forest zones. Diversity is lower - about 100 trees/ha, but the majority of the most common species in Ghana have their 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 rainfall is 1250-1750mm.
- Moist Semideciduous NW - Has similar attributes as the Moist Semi-deciduous south-east zone. Most of the gazetted forest reserves are found within this zone.
- 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 rainfall exceeding 1250-1750mm. The soils are much richer than those in Moist and Wet Evergreen, however species diversity is much lower.
- Wet Evergreen - This is forest that remains green throughout the year and does not shed leaves. Upper canopy trees rarely exceed 40m high. This stratum is very rich in species diversity and annual rain fall exceeds 1750mm. The soil PH is 3.8-4.3.
- Dry Semideciduous - It has a wide range of annual rainfall (1000 -1500mm), it is heavily degraded because of frequent wildfires. Large portion of the gazette natural forests have been converted to plantations. The vertical structure is between 30-45-m. Most gazette forest reserves are found within this zone.
- Savannah - 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 a management practice for the rangelands.
- Southern Marginal - The Southern Marginal forest is shorter than 30m, has thick undergrowth and may include high densities of multiple species.

Figure 13 shows the distribution of the nine vegetation zones in Ghana's territory.

Figure 13 Ghana's distribution of Vegetation Zones .



Level 1: CROPLAND (C)

This category includes cropped land, currently cropped or in fallow, including rice fields, and agroforestry systems where the vegetation structure falls below the thresholds of the forest definition. It includes trees managed for agricultural purposes such as rubber, cocoa, oil palm, fruit trees etc. Based on the survey from Collect Earth, Cropland is characterized as a 0.5 ha area that has crop cover greater than 20% where Settlement is less than 20%.

Level 2:

- Annual Crop - these are plants that perform their entire life cycle within a single growing season. All roots, stems and leaves of the plants are removed or die annually. In Ghana such crops include, maize, etc.
- Perennial Crop - these are crops that remain on the ground for more than two years. Example of perennial crops in Ghana include cocoa, oil palm and rubber plantations.
- Fallow: agricultural lands left to rejuvenate, recover and restore. Average time is 2 to 3 years, up to 5 years. It varies from locality to locality depending on availability of land.

Level 1: GRASSLAND (G)

This category includes rangelands and pasture land that are not considered Cropland. It also includes systems with woody vegetation and other non-grass vegetation such as herbs and brushes that fall below the thresholds in the forest definition. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvopastoral systems.

Level 1: WETLANDS (W)

These include land that is covered or saturated by water for all or part of the year and that does not fall into the Forest Land, cropland, Grassland or Settlements categories. It also includes reservoirs, natural rivers and lakes.

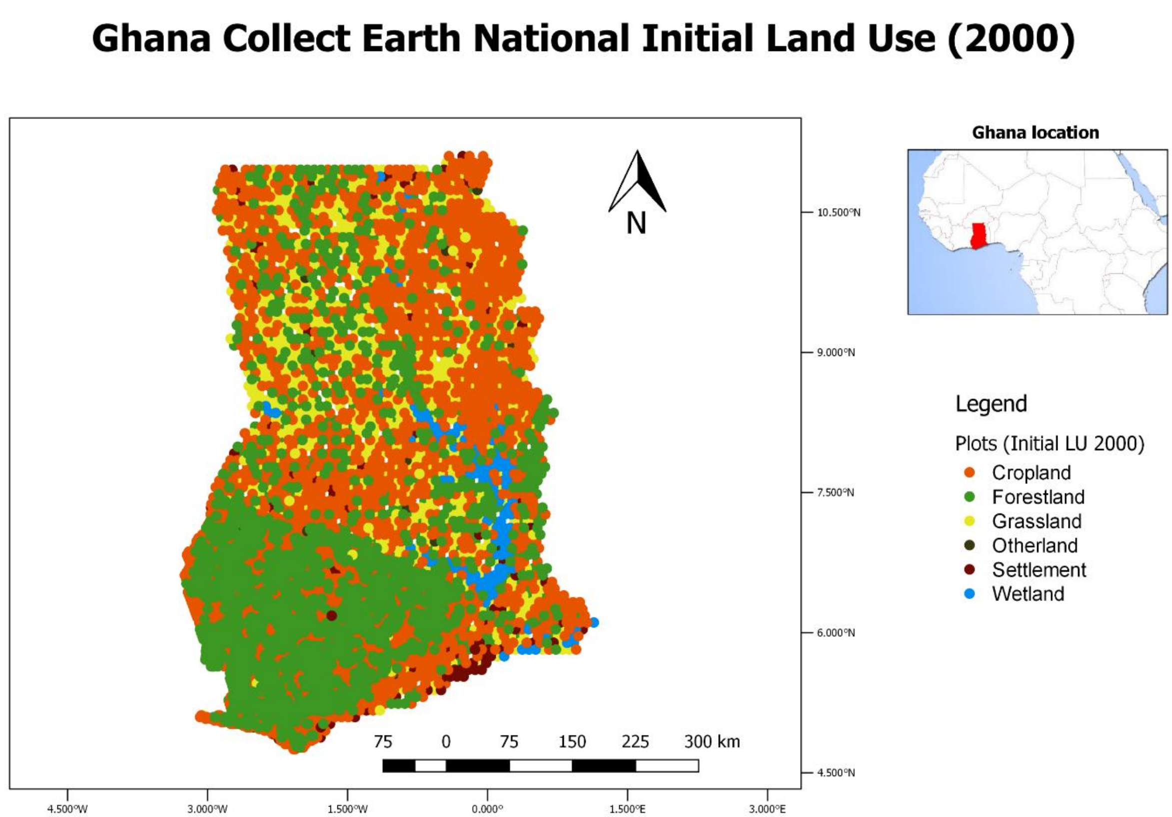
Level 1: SETTLEMENTS (S)

This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories.

Level 1: OTHER LAND (O)

This category includes bare soil, rock, mining operations and all land areas that do not fall into any of the other five categories.

Figure 14 Ghana Collect Earth National Initial Land Use (2000)



8.6 National Forest Inventory

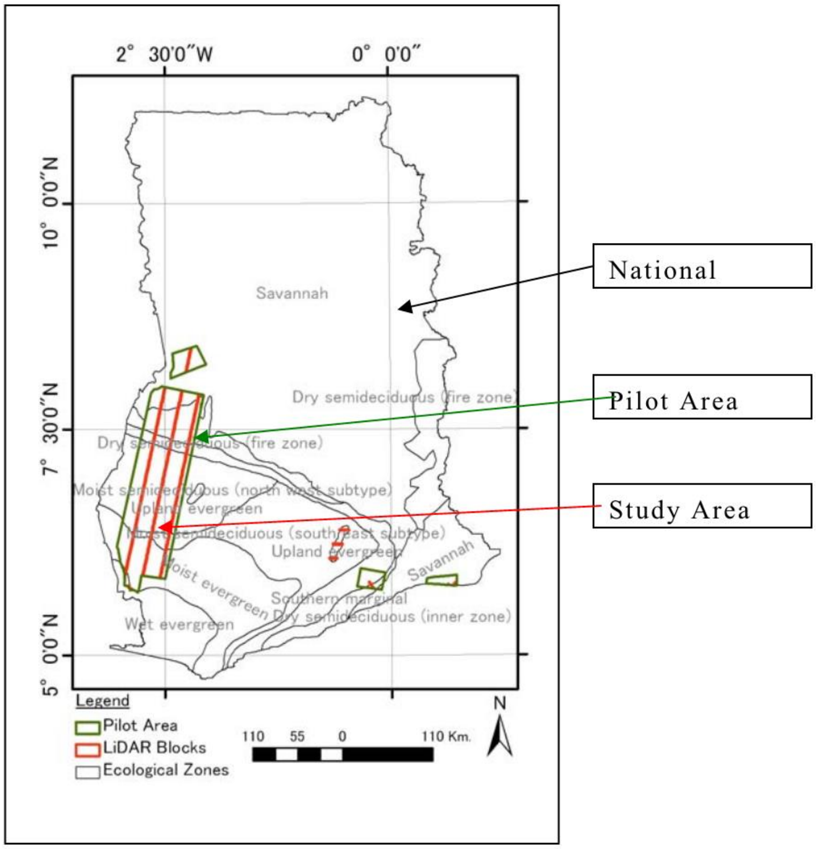
The Report on Mapping of Forest Cover and Carbon Stock in Ghana[8] (2013), result from a joint initiative between the Government of Japan (GoJ) and the Government of Ghana (GoG) a part of the Forest Preservation Programme (FPP), includes the estimation of carbon stocks in forests from field sampling and the use of LiDAR (Light Detection And Ranging) technoloty (Study Area). Remotely sensed data from Landsat, SAR data from PALSAR sensor onboard ALOS and DMC were used to create a historical analysis of land-use change between 1990 and 2010. Mapping Consultant's Services (MCS) also undertook field plot measurements alongside LiDAR surveys in sub-national demonstration areas for biomass and carbon estimation. One of the objectives of the project was to establish a good correlation between field sample measurements and LiDAR measurements and satellite data to improve the extrapolation of carbon estimates using these sampling strategies.

The FPP Project – sampling design

The project involved three levels of analysis (refer to Figure 15), each carried out in three different areas, as indicated in Figure 9. The first level was conducted at national level, covering the entire national territory of approximately 23,915,421 ha (239,915 km^2) for “Mapping and Historical Forest Resource Change Assessment”; the second level was carried out in a pilot area of 1,718,600 ha (17,186 km^2) and aimed at a detailed “Forest Resource Mapping” composed of two main blocks (south-west) and two smaller blocks (south-east) of the country; and finally, a third level covering a study area of 86,400 ha (864 km^2) with LiDAR transects over the entire Pilot Area and the Atiwa forest reserve for “Forest Biomass Inventory”.

[8] Report on Mapping of Forest Cover and Carbon Stock in Ghana. PASCO CORPORATION, Japan, in collaboration with FC-RMSC, CSIR-FORIG and CSIR-SRI, Ghana. April, 2013.

Figure 15 Location of the three areas covered by the FPP project: national and pilot and study areas



The project had defined a list of expected results, some of which of direct interest for this submission, such as allometric equations and carbon stock models based on vegetation zones, lookup tables for biomass and carbon stock estimation for all terrestrial pools, and estimated biomass and carbon stock for a pilot area and extrapolation to national level.

The FPP provided estimates for above and below-ground biomass (AGB and BGB, respectively), as well as for litter (L), dead wood (DW) and soil organic carbon (SOC) for all nine vegetation zones, distinguished by open and closed forests, generating 18 classes in total. The estimated results were analyzed for their appropriateness to be used in this submission which will be indicated in each relevant section.

Sample plots have been distributed over the vegetation zones according to the scheme indicated in Table 9.

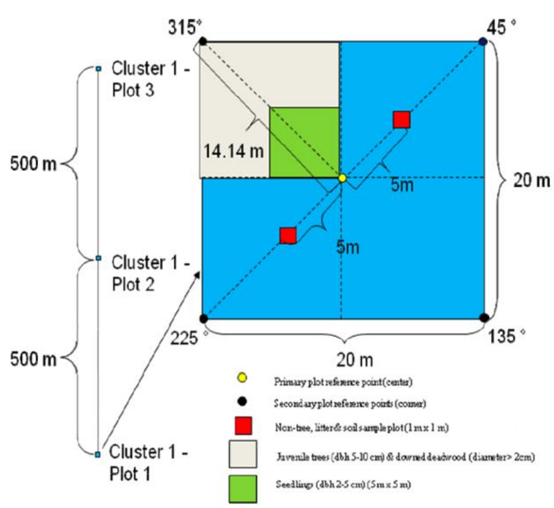
Table 8 Sample plots distributed among the vegetation zones.

Zone		Number of plots
Savannah, Dry Semideciduous (fire zone), Dry Semideciduous (inner zone)		30 sample clusters, total 90 plots
Moist semideciduous North-West zone		40 sample clusters, total 120 plots
Moist semideciduous South-East zone, Moist Evergreen, Wet Evergreen		30 sample clusters, total 90 plots
Upland Evergreen		39 randomly sampled plots
Southern Margin or Marginal		12 randomly sampled plots
Mangroves		10 randomly sampled plots

Each cluster consisted of three plots, with the sample plots distributed within a distance of 500 m of each other balancing between transportation time, overall costs and to avoid spatial autocorrelation effects between plots. The primary cluster reference point is the centre point of the most southern plot within a cluster. The pilot area extent and clusters along with 9 vegetation zones division are shown in Figure 9 above. The planned field sampling intensity over the pilot area of 9 vegetation zones and mangrove forests corresponds to 0.0008%. This can be considered extremely low to produce accurate plot-based mean values but meets the minimum conditions of LiDAR-based aboveground carbon modeling over three aggregated sampling strata.

Plots of 400 m^2 (20 x 20 meters) were established, as indicated in Figure 16. Tally and standing dead trees were measured over the entire plot. Juvenile trees and downed deadwood were enumerated from 10 x 10 meters subplots. The sub-plot size for seedling measurements was 5 x 5 meters. Litter, non-tree and soil samples were collected from two 1- m^2 subplots located on the south-west – north-east diagonal line, 5 meters apart from the center of the plot.

Figure 16 A sample cluster with sub-plots.



8.7 Category-level methodologies for estimating GHG emissions and removals

The FREL/FRL was constructed from a series of steps and using a range of data from diverse sources. The estimation of the GHG emissions and removals was based on a combination of: (a) country-specific methods and data; (b) IPCC methodologies and methods; and (c) emission factors (EFs). The methods were consistent with the 2006 IPCC Guidelines and are, to the extent possible, in line with international practice. IPCC tiers 1, 2 and 3 were applied.

For the estimation of the changes in biomass carbon stocks and non-CO_2 emissions, Ghana applied the methodologies in the 2006 IPCC GLs, Volume 4, Chapter 2 “Generic Methodologies Applicable to Multiple Land-use Categories”. It includes the analysis for Forest Land remaining in the same land-use category, land converted to Forest Land and Forest Land converted to another land-use category.

The methods, assumptions and additional definitions used in this FREL/FRL submission are described in sequence.

Overview of carbon stock change estimation

The annual carbon stock change for the Agriculture, Forestry and Other Land Uses (AFOLU) sector is estimated as the sum of changes in all land-use categories, as indicated below.

Annual Carbon Stock Changes for the entire AFOLU Sector estimated as the sum of changes in all land-use categories (Equation 2.1, Ch2, V4)

$$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{SL} + \Delta C_{OL}$$

Where:

ΔC = carbon stock change

Indices denote the following land-use categories:

AFOLU = Agriculture, Forestry and Other Land Use
F = Forest Land
C = Cropland
G = Grassland
W = Wetlands
S = Settlements
O = Other Land

Table 9 presents the land-use categories and sub-categories included in the estimation of the net emissions and removals.

Table 9 Land-use categories and sub-categories defined for the FREL/FRL.

GHANA	
LU	Sub-Category
F	Wet Evergreen
	Moist Evergreen
	Moist Semideciduous - SE
	Moist Semideciduous - NW
	Upland Evergreen
	Dry Semideciduous (Inner Zone)
	Dry Semideciduous (Fire Zone)
	Savannah
	Southern Marginal
C	Annual crops
	Perennial crops
	Fallow Lands
G	Grassland
W	Wetlands
S	Settlements
O	Other lands

Annual carbon stock changes for a land-use category as a sum of changes in each stratum within the category (Equation 2.2, Ch2, V4)

$$\Delta C_{LU} = \Sigma\ \Delta C_{LUi}$$

Where:

ΔC_{LU} = carbon stock changes for a land-use (LU) category
i = denotes a specific stratum or subdivision within the land-use category (by any combination of species, climatic zone, ecotype, management regime, etc.), *i* = 1 ton.

Annual carbon stock changes for a stratum of a land-use category as a sum of changes in all pools (Equation 2.3, Ch2, V4)

$$\Delta C_{LUi} = \Delta C_{AGB} + \Delta C_{BGB} + \Delta C_{LI} + \Delta C_{DW} + \Delta C_{SO} + \Delta C_{HWP}$$

Where:

ΔC_{LUi} = carbon stock changes for a stratum of a land-use category Subscripts denote the following carbon pools:

AGB = above-ground biomass
BGB = below-ground biomass
DW= deadwood
LI = litter
SO = soils
HWP = harvested wood products

Table 10 shows the carbon pools included and excluded in the construction of the FREL/FRL.

Table 10 Carbon pools data sources.

	Included
ΔC_{AB}	Yes
ΔC_{BB}	Yes
ΔC_{DOM}	Yes
ΔC_{SOC}	No
ΔC_{HWP}	No

Clarification Note:

The pool Harvested Wood Products was not included in the construction of the FREL/FRL due to lack of data. A preliminary on Soil Organic Carbon assessment (refer to Annex I) indicates that this pool might not be significant. However, more in-depth analysis is on-going; reason why SOC was excluded in this submission.

Annual carbon stock change in a given pool as a function of gains and losses (gain-loss method) (Equation 2.4, Ch2, V4)

$$\Delta C = \Delta C_G - \Delta C_L$$

Where:

ΔC = annual carbon stock change in the pool, tonnes C yr^{-1}

ΔC_G = annual gain of carbon, tonnes C yr^{-1}

ΔC_L = annual loss of carbon, tonnes C yr^{-1}

Change in biomass carbon stocks (above-ground biomass and below-ground biomass) in land remaining in the same land-use category

Annual change in carbon stocks in biomass in land remaining in a particular land-use category (gain-loss method) (Equation 2.7, Ch2, V4)

$$\Delta C_B = \Delta C_G - \Delta C_L$$

Where:

ΔC_B = annual change in carbon stocks in biomass for each land sub-category, considering the total area, tonnes C yr^{-1}

ΔC_G = annual increase in carbon stocks due to biomass growth for each land sub-category, considering the total area, tonnes C yr^{-1}

ΔC_L = annual decrease in carbon stocks due to biomass loss for each land sub-category, considering the total area, tonnes C yr^{-1}

Annual increase in biomass carbon stocks due to biomass increment in land remaining in the same land-use category (Equation 2.9, Ch2, V4)

$$\Delta C_G = \Sigma (A_{i,j} \bullet G_{TOTALi,j} \bullet Cf_{i,j})$$

Where:

ΔC_G = annual increase in biomass carbon stocks due to biomass growth in land remaining in the same land-use category by vegetation type and climatic zone, tonnes C yr^{-1}

A = area of land remaining in the same land-use category, ha

G_{TOTAL} = mean annual biomass growth, tonnes d. m. ha^{-1} yr^{-1}

i = ecological zone (*i* = 1 to *n*)

j = climate domain (*j* = 1 to *m)*

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$

Table 11 provides the values used in this submission for the Carbon Fraction (CF) for each vegetation zone in Forest Land, for the Cropland sub-categories, and for Grassland. Table 13 indicates the source of Forest Land, Cropland and Grassland areas.

Table 11 Carbon Fraction(CF) of dry matter applied in Forest Land, Cropland and Grassland, tonne C (tonne d.m.)-1.

CF: Carbon Fraction				
LU	Sub-Category	Value	Range / Error	Source
F	Wet Evergreen	0.47	(0.44 - 0.49)	2006 IPCC Guidelines, V4, Ch4, Table 4.3 for tropical and sub-tropical domain, for all parts of the tree.
	Moist Evergreen	0.47	(0.44 - 0.49)	2006 IPCC Guidelines, V4, Ch4, Table 4.3 for tropical and sub-tropical domain, for all parts of the tree.

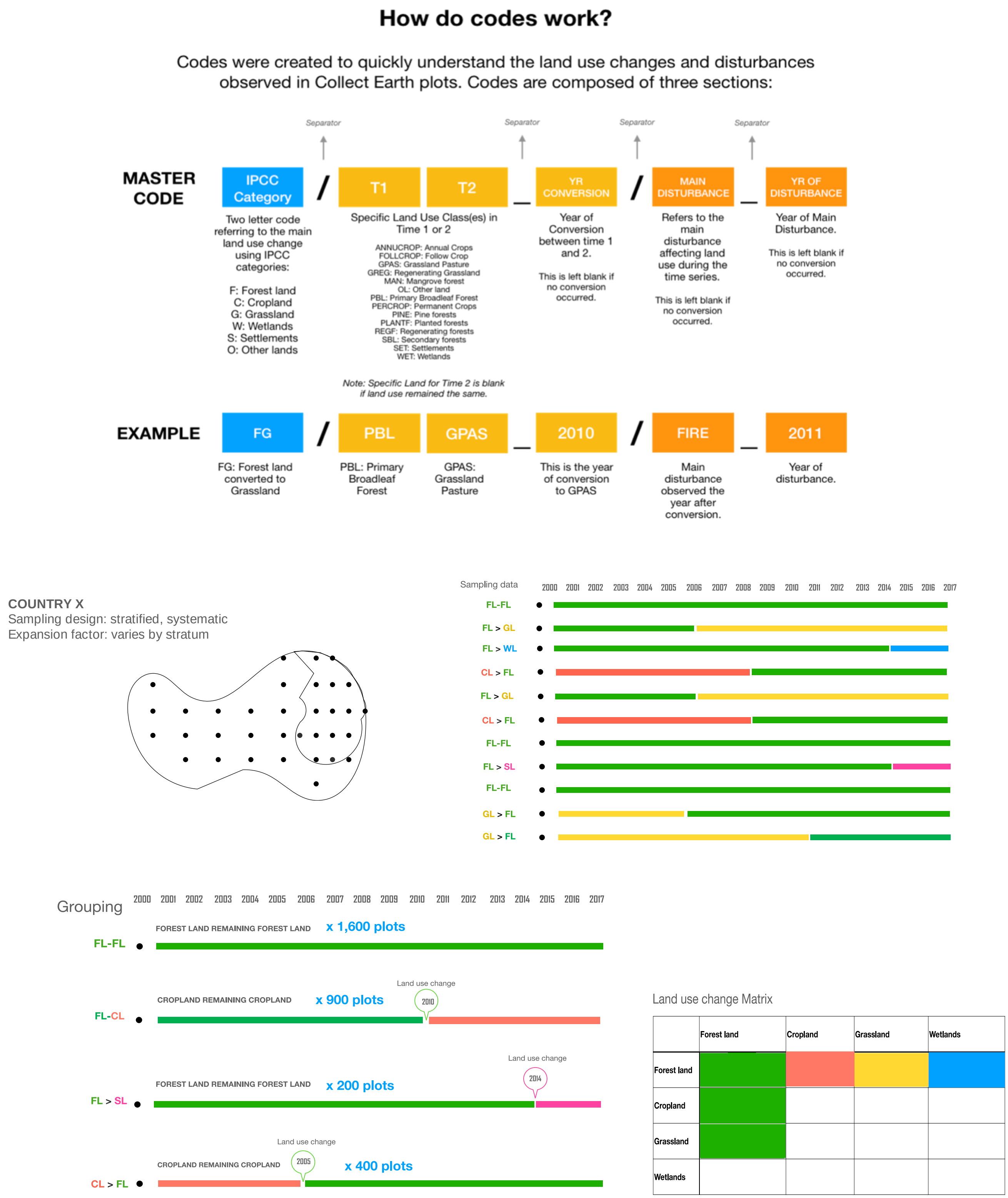
	Moist Semideciduous SE	0.47	(0.44 - 0.49)	2006 IPCC Guidelines, V4, Ch4, Table 4.3 for tropical and sub-tropical domain, for all parts of the tree.
	Moist Semideciduous NW	0.47	(0.44 - 0.49)	2006 IPCC Guidelines, V4, Ch4, Table 4.3 for tropical and sub-tropical domain, for all parts of the tree.
	Upland Evergreen	0.47	(0.44 - 0.49)	2006 IPCC Guidelines, V4, Ch4, Table 4.3 for tropical and sub-tropical domain, for all parts of the tree.
	Dry Semideciduous (Inner Zone)	0.47	(0.44 - 0.49)	2006 IPCC Guidelines, V4, Ch4, Table 4.3 for tropical and sub-tropical domain, for all parts of the tree.
	Dry Semideciduous (Fire Zone)	0.47	(0.44 - 0.49)	2006 IPCC Guidelines, V4, Ch4, Table 4.3 for tropical and sub-tropical domain, for all parts of the tree.
	Savannah	0.47	(0.44 - 0.49)	2006 IPCC Guidelines, V4, Ch4, Table 4.3 for tropical and sub-tropical domain, for all parts of the tree.
	Southern Marginal	0.47	(0.44 - 0.49)	2006 IPCC Guidelines, V4, Ch4, Table 4.3 for tropical and sub-tropical domain, for all parts of the tree.
C	Annual crops	0.47	75%	2019 IPCC Refinement, chapter 5, section 5.3.1.2, Table 5.8,
	Perennial crops	0.5	75%	2006 IPCC, V4, CH5, Section 5.2.1.4, Step 4; no error or range provided; assumes same error as for grassland
	Fallow Lands	0.5	75%	2006 IPCC, V4, CH5, Section 5.2.1.4, Step 4; no range or range provided; assumes same error as for grassland
G	Grassland	0.47	75%	2006 IPCC, V4, CH6, Section 6.2.1.4, Step 3; error range in 2019 IPCC Refinement, chapter 5, section 5.3.1.2, Table 5.8
W	Wetlands	0		Assumed to be zero
S	Settlements	0		Assumed to be zero
O	Other lands	0		Assumed to be zero

Table 12. Source of areas of land remaining in the same land-use category (ha) and period considered.

A: area of land remaining in the same land-use category			
LU	Sub-Category	Source	Notes
F	Wet Evergreen	Collect Earth	Years 2000 – 2015
	Moist Evergreen	Collect Earth	Years 2000 – 2015
	Moist Semideciduous SE	Collect Earth	Years 2000 – 2015
	Moist Semideciduous NW	Collect Earth	Years 2000 – 2015
	Upland Evergreen	Collect Earth	Years 2000 – 2015
	Dry Semideciduous (Inner Zone)	Collect Earth	Years 2000 – 2015
	Dry Semideciduous (Fire Zone)	Collect Earth	Years 2000 – 2015
	Savannah	Collect Earth	Years 2000 – 2015
	Southern Marginal	Collect Earth	Years 2000 – 2015
C	Annual crops	Collect Earth	Years 2000 – 2015
	Perennial crops	Collect Earth	Years 2000 – 2015
	Fallow Lands	Collect Earth	Years 2000 – 2015
G	Grasslands	Collect Earth	Years 2000 – 2015
W	Wetlands	Collect Earth	Years 2000 – 2015
S	Settlements	Collect Earth	Years 2000 – 2015
O	Other lands	Collect Earth	Years 2000 – 2015

Clarification Notes

This section includes information on the Collect Earth assessment *(See Step3a AD-Database in attached Excel file).* A coding system was created to aggregate plots with the same land use or land-use change. Codes depict a single trajectory or dynamic of each plot informing land use, land-use change (if any) and disturbances (if any) *(See Step3b AD-Code in attached Excel file).* These trajectories, in the form of a code (Figure 17), were created to simplify the analysis as it sums up all plots with the same trajectory, represented in the same code, reducing considerably the number of plots for which IPCC equations were applied.



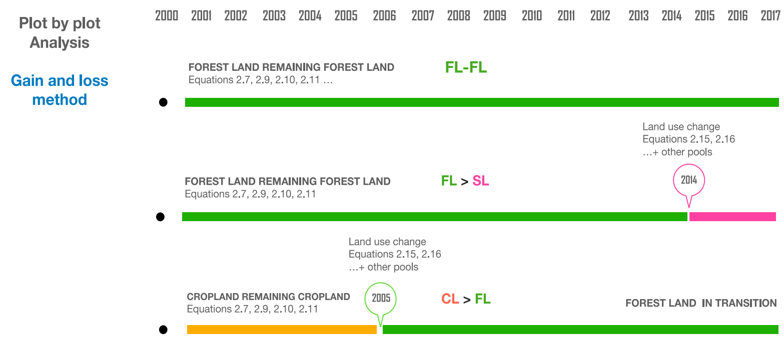


Figure 17 Coding System for land use and land-use change representation.

The area that each trajectory represents is estimated by multiplying the number of plots of each trajectory by the corresponding expansion factor, which was calculated dividing the total surface of each stratum by the total number of plots in each specific stratum (see Table 14).

Table 13. Expansion Factors by Strata (Vegetation Zone).

WEIGHTS PER STRATUM / EXPANSION FACTORS				
Code	Strata	Area per stratum (Ha)	Number of sample units per stratum	Expansion factor (the area that each sample in the stratum represents) (ha)
MEVER.2	Moist evergreen 2x2	886,983	1393	637
MEVER.4	Moist evergreen 4x4	945,406	744	1271
MSEMNW.2	Moist SemiD NW 2x2	962,079	1557	618
MSEMNW.4	Moist SemiD NW 4x4	595,511	491	1213
MSEMSE.2	Moist SemiD SE 2x2	989,659	1546	640
MSEMSE.4	Moist SemiD SE 4x4	737,423	609	1211
WETEVER.2	Wet evergreen 2x2	457,198	754	606
WETEVER.4	Wet evergreen 4x4	277,565	229	1212
UPEVER.1	Upland evergreen 1x1	62,601	393	159
.8	Remainder of the country 8x8	18,000,996	2730	6594
	Total area of the country	23,915,421		

Then, to facilitate the understanding by Land-Use Classes, the Pivot table information was distributed by F (Forest Land) (refer to Table 15), C (Cropland) (refer to Table 16), G (Grassland) (refer to Table 17), W (Wetlands) (refer to Table 18), S (Settlements) (refer to Table 19), O (Other Land) (refer to Table 20). This approach allows including all the previous descriptions in one single analysis, thus explaining why it is used for the calculations instead of the Land-Use Change and Disturbance Matrices *(See Step 4a. AD-PlotSum in attached Excel file).*

Table 14. Pivot table information for Forest Land.

FOREST LAND		
Total Sum	3,234	5,454,405
Row Labels	Count of Transition Coding	Area [Ha]
FF/WETEVER/_/WETEVER.2	396	240120
FF/WETEVER/_/WETEVER.4	25	30302
FF/WETEVER/Dist_2010/WETEVER.4	1	1212
FF/WETEVER/Dist_2013/WETEVER.2	1	606
FF/WETEVER/Dist_2015/WETEVER.2	2	1213
FF/WETEVER/Dist_2017/WETEVER.4	1	1212
FF/WETEVER/Dist_2019/WETEVER.2	1	606
FF/WETEVER/logging_2008/WETEVER.2	1	606
FF/WETEVER/logging_2014/WETEVER.2	1	606
FF/WETEVER/logging_2018/WETEVER.2	1	606
FF/MEVER/_/MEVER.2	762	485198
FF/MEVER/_/MEVER.4	80	101657
FF/MEVER/Dist_2006/MEVER.4	1	1271
FF/MEVER/Dist_2008/MEVER.4	1	1271
FF/MEVER/Dist_2009/MEVER.2	1	637
FF/MEVER/Dist_2009/MEVER.4	1	1271
FF/MEVER/Dist_2012/MEVER.4	1	1271
FF/MEVER/Dist_2013/MEVER.2	1	637
FF/MEVER/Dist_2014/MEVER.2	2	1273
FF/MEVER/Dist_2015/MEVER.2	2	1273
FF/MEVER/Dist_2016/MEVER.2	1	637
FF/MEVER/Dist_2016/MEVER.4	1	1271
FF/MEVER/Dist_2017/MEVER.2	2	1273
FF/MEVER/Dist_2017/MEVER.4	2	2541
FF/MEVER/Dist_2019/MEVER.2	1	637
FF/MEVER/logging_2008/MEVER.2	1	637
FF/MEVER/logging_2009/MEVER.2	3	1910
FF/MEVER/logging_2010/MEVER.2	1	637
FF/MEVER/logging_2011/MEVER.2	1	637
FF/MEVER/logging_2013/MEVER.2	1	637
FF/MEVER/logging_2014/MEVER.2	1	637
FF/MEVER/logging_2015/MEVER.2	4	2547
FF/MEVER/logging_2016/MEVER.2	2	1273
FF/MEVER/logging_2017/MEVER.2	1	637
FF/MEVER/logging_2018/MEVER.2	1	637
FF/MEVER/logging_2019/MEVER.2	1	637
FF/MSEMSE/_/MSEMSE.2	429	274621
FF/MSEMSE/_/MSEMSE.4	59	71442
FF/MSEMSE/Dist_2000/MSEMSE.4	2	2422
FF/MSEMSE/Dist_2010/MSEMSE.2	1	640
FF/MSEMSE/Dist_2011/MSEMSE.2	1	640
FF/MSEMSE/Dist_2012/MSEMSE.2	2	1280
FF/MSEMSE/Dist_2013/MSEMSE.2	3	1920
FF/MSEMSE/Dist_2013/MSEMSE.4	1	1211
FF/MSEMSE/Dist_2015/MSEMSE.4	1	1211
FF/MSEMSE/Dist_2016/MSEMSE.2	1	640

FF/MSEMSE/Dist_2019/MSEMSE.2	1	640
FF/MSEMSE/Dist_2019/MSEMSE.4	1	1211
FF/MSEMSE/fire_2013/MSEMSE.2	2	1280
FF/MSEMSE/logging_2006/MSEMSE.4	1	1211
FF/MSEMSE/logging_2008/MSEMSE.2	1	640
FF/MSEMSE/logging_2011/MSEMSE.2	1	640
FF/MSEMSE/logging_2012/MSEMSE.2	2	1280
FF/MSEMSE/logging_2013/MSEMSE.2	1	640
FF/MSEMSE/logging_2014/MSEMSE.2	3	1920
FF/MSEMSE/logging_2015/MSEMSE.2	1	640
FF/MSEMSE/logging_2017/MSEMSE.2	2	1280
FF/MSEMSE/logging_2017/MSEMSE.4	1	1211
FF/MSEMSE/logging_2019/MSEMSE.2	4	2561
FF/MSEMNW/_/MSEMNW.2	560	346027
FF/MSEMNW/_/MSEMNW.4	27	32747
FF/MSEMNW/Dist_2000/MSEMNW.2	1	618
FF/MSEMNW/Dist_2006/MSEMNW.2	1	618
FF/MSEMNW/Dist_2010/MSEMNW.2	1	618
FF/MSEMNW/Dist_2012/MSEMNW.2	2	1236
FF/MSEMNW/Dist_2012/MSEMNW.4	1	1213
FF/MSEMNW/Dist_2013/MSEMNW.4	2	2426
FF/MSEMNW/Dist_2014/MSEMNW.2	1	618
FF/MSEMNW/Dist_2015/MSEMNW.2	1	618
FF/MSEMNW/Dist_2017/MSEMNW.2	2	1236
FF/MSEMNW/Dist_2018/MSEMNW.2	1	618
FF/MSEMNW/Dist_2019/MSEMNW.2	1	618
FF/MSEMNW/logging_2006/MSEMNW.2	1	618
FF/MSEMNW/logging_2008/MSEMNW.2	2	1236
FF/MSEMNW/logging_2009/MSEMNW.2	1	618
FF/MSEMNW/logging_2010/MSEMNW.2	1	618
FF/MSEMNW/logging_2011/MSEMNW.2	1	618
FF/MSEMNW/logging_2012/MSEMNW.2	1	618
FF/MSEMNW/logging_2013/MSEMNW.2	2	1236
FF/MSEMNW/logging_2013/MSEMNW.4	1	1213
FF/MSEMNW/logging_2014/MSEMNW.2	4	2472
FF/MSEMNW/logging_2015/MSEMNW.2	12	7415
FF/MSEMNW/logging_2016/MSEMNW.2	1	618
FF/MSEMNW/logging_2017/MSEMNW.2	2	1236
FF/MSEMNW/logging_2017/MSEMNW.4	1	1213
FF/MSEMNW/logging_2018/MSEMNW.2	1	618
FF/MSEMNW/logging_2019/MSEMNW.2	4	2472
FF/UPEVER/_/UPEVER.1	173	27557
FF/UPEVER/Dist_2000/UPEVER.1	1	159
FF/UPEVER/Dist_2009/UPEVER.1	1	159
FF/UPEVER/Dist_2014/UPEVER.1	1	159
FF/UPEVER/Dist_2017/UPEVER.1	1	159
FF/UPEVER/logging_2003/UPEVER.1	1	159
FF/UPEVER/logging_2007/UPEVER.1	2	319
FF/UPEVER/logging_2009/UPEVER.1	1	159
FF/UPEVER/logging_2015/UPEVER.1	1	159
FF/UPEVER/logging_2016/UPEVER.1	2	319
FF/UPEVER/logging_2017/UPEVER.1	3	478
FF/UPEVER/logging_2018/UPEVER.1	1	159
FF/DRYFIRE/_/DRYFIRE.8	75	494533
FF/DRYINNER/_/DRYINNER.8	37	243970
FF/DRYINNER/Dist_2013/DRYINNER.8	1	6594
FF/DRYINNER/Dist_2017/DRYINNER.8	1	6594
FF/SAV/_/SAV.8	417	2749603

FF/SAV/Dist_2011/SAV.8	1	6594
FF/SAV/Dist_2018/SAV.8	1	6594
FF/SAV/fire_2011/SAV.8	1	6594
FF/SAV/fire_2012/SAV.8	1	6594
FF/SAV/fire_2014/SAV.8	2	13188
FF/SAV/fire_2016/SAV.8	2	13188
FF/SAV/fire_2018/SAV.8	1	6594
FF/SAV/logging_2001/SAV.8	1	6594
FF/SAV/logging_2012/SAV.8	1	6594
FF/SAV/logging_2018/SAV.8	1	6594
FF/SOUTH/_/SOUTH.8	7	46156
CF/CANN>DRYFIRE_2014/_/DRYFIRE.8	1	6594
CF/CANN>DRYFIRE_2015/_/DRYFIRE.8	1	6594
CF/CANN>DRYFIRE_2017/_/DRYFIRE.8	2	13188
CF/CANN>DRYINNER_2015/_/DRYINNER.8	1	6594
CF/CANN>DRYINNER_2018/_/DRYINNER.8	1	6594
CF/CANN>MEVER_2012/_/MEVER.2	1	637
CF/CANN>MEVER_2015/_/MEVER.4	1	1271
CF/CANN>MSEMNW_2015/_/MSEMNW.2	1	618
CF/CANN>MSEMNW_2019/_/MSEMNW.2	1	618
CF/CANN>MSEMSE_2010/_/MSEMSE.2	1	640
CF/CANN>MSEMSE_2013/_/MSEMSE.2	1	640
CF/CANN>MSEMSE_2014/_/MSEMSE.2	1	640
CF/CANN>MSEMSE_2014/_/MSEMSE.4	1	1211
CF/CANN>MSEMSE_2017/_/MSEMSE.2	1	640
CF/CANN>SAV_2009/_/SAV.8	1	6594
CF/CANN>SAV_2011/_/SAV.8	1	6594
CF/CANN>SAV_2012/_/SAV.8	1	6594
CF/CANN>SAV_2016/_/SAV.8	1	6594
CF/CANN>SAV_2017/_/SAV.8	1	6594
CF/CPER>MEVER_2008/_/MEVER.2	1	637
CF/CPER>MSEMSE_2009/_/MSEMSE.4	1	1211
CF/CPER>MSEMSE_2014/_/MSEMSE.2	1	640
CF/CPER>SAV_2016/_/SAV.8	1	6594
GF/GRASS>MSEMNW_2011/_/MSEMNW.2	1	618
GF/GRASS>MSEMSE_/_/MSEMSE.2	1	640
GF/GRASS>SAV_2012/_/SAV.8	1	6594
GF/GRASS>SAV_2013/_/SAV.8	2	13188
GF/GRASS>SAV_2014/_/SAV.8	1	6594
GF/GRASS>SAV_2015/_/SAV.8	1	6594
SF/SET>MEVER_2013/_/MEVER.4	1	1271
OF/OTHER>MSEMNW_2014/logging_2013/MSEMNW.2	1	618

Table 15. Pivot table information for Cropland.

CROPLANDS		
Total Sum	5,976	12,659,129
Row Labels	Count of Transition Coding	Area [Ha]
CC/CANN/_/DRYFIRE.8	68	448376
CC/CANN/_/DRYINNER.8	48	316501
CC/CANN/_/MEVER.2	64	40752
CC/CANN/_/MEVER.4	83	105469
CC/CANN/_/MSEMNW.2	179	110605
CC/CANN/_/MSEMNW.4	91	110370
CC/CANN/_/MSEMNW.8	1	6594
CC/CANN/_/MSEMSE.2	136	87059

Cc/CANN/_/MSEMSE.4	82	99292
CC/CANN/_/SAV.8	1013	6679490
CC/CANN/_/SOUTH.8	8	52750
CC/CANN/_/UPEVER.1	28	4460
CC/CANN/_/WETEVER.2	40	24255
CC/CANN/_/WETEVER.4	24	29090
CC/CFA/_/MEVER.2	18	11461
CC/CFA/_/MEVER.4	27	34309
CC/CFA/_/MSEMNW.2	32	19773
CC/CFA/_/MSEMNW.4	34	41237
CC/CFA/_/MSEMSE.2	46	29447
CC/CFA/_/MSEMSE.4	34	41170
CC/CFA/_/UPEVER.1	8	1274
CC/CFA/_/WETEVER.2	11	6670
CC/CFA/_/WETEVER.4	7	8485
CC/CPER/_/DRYFIRE.8	23	151657
CC/CPER/_/DRYINNER.8	29	191219
CC/CPER/_/MEVER.2	477	303726
CC/CPER/_/MEVER.4	482	612481
CC/CPER/_/MSEMNW.2	640	395460
CC/CPER/_/MSEMNW.4	253	306852
CC/CPER/_/MSEMSE.2	787	503791
CC/CPER/_/MSEMSE.4	329	398378
CC/CPER/_/SAV.8	95	626408
CC/CPER/_/SOUTH.8	8	52750
CC/CPER/_/UPEVER.1	127	20230
CC/CPER/_/WETEVER.2	281	170388
CC/CPER/_/WETEVER.4	157	190296
CC/CPER/_/WETEVER.8	1	6594
FC/WETEVER>CANN_2013/_/WETEVER.4	1	1212
FC/WETEVER>CFA_2015/_/WETEVER.2	1	606
FC/WETEVER>CPER_2010/_/WETEVER.2	1	606
FC/WETEVER>CPER_2013/_/WETEVER.2	2	1213
FC/WETEVER>CPER_2014/_/WETEVER.2	1	606
FC/WETEVER>CPER_2016/_/WETEVER.4	1	1212
FC/WETEVER>CPER_2017/_/WETEVER.4	1	1212
FC/MEVER>CANN_2009/_/MEVER.4	1	1271
FC/MEVER>CANN_2013/_/MEVER.4	1	1271
FC/MEVER>CANN_2014/_/MEVER.4	1	1271
FC/MEVER>CANN_2015/_/MEVER.2	2	1273
FC/MEVER>CFA_2012/_/MEVER.2	1	637
FC/MEVER>CFA_2014/_/MEVER.4	1	1271
FC/MEVER>CPER_/_/MEVER.4	1	1271
FC/MEVER>CPER_2004/_/MEVER.2	1	637
FC/MEVER>CPER_2006/_/MEVER.2	1	637
FC/MEVER>CPER_2007/_/MEVER.4	1	1271
FC/MEVER>CPER_2008/_/MEVER.4	1	1271
FC/MEVER>CPER_2011/_/MEVER.4	1	1271
FC/MEVER>CPER_2013/_/MEVER.2	2	1273
FC/MEVER>CPER_2013/_/MEVER.4	3	3812
FC/MEVER>CPER_2014/_/MEVER.2	1	637
FC/MEVER>CPER_2014/_/MEVER.4	3	3812
FC/MEVER>CPER_2015/_/MEVER.2	2	1273
FC/MEVER>CPER_2019/_/MEVER.2	1	637
FC/MSEMSE>CANN_2003/_/MSEMSE.2	1	640
FC/MSEMSE>CANN_2006/_/MSEMSE.2	1	640
FC/MSEMSE>CANN_2009/_/MSEMSE.2	1	640
FC/MSEMSE>CANN_2011/_/MSEMSE.2	3	1920

FC/MSEMSE>CANN_2012/_/MSEMSE.2	5	3201
FC/MSEMSE>CANN_2012/_/MSEMSE.4	1	1211
FC/MSEMSE>CANN_2013/_/MSEMSE.2	1	640
FC/MSEMSE>CANN_2014/_/MSEMSE.4	2	2422
FC/MSEMSE>CANN_2018/_/MSEMSE.2	1	640
FC/MSEMSE>CANN_2019/_/MSEMSE.2	1	640
FC/MSEMSE>CFA_2013/_/MSEMSE.4	1	1211
FC/MSEMSE>CFA_2014/_/MSEMSE.2	1	640
FC/MSEMSE>CPER_2002/_/MSEMSE.2	1	640
FC/MSEMSE>CPER_2003/_/MSEMSE.2	1	640
FC/MSEMSE>CPER_2006/_/MSEMSE.2	2	1280
FC/MSEMSE>CPER_2007/_/MSEMSE.2	1	640
FC/MSEMSE>CPER_2008/_/MSEMSE.2	1	640
FC/MSEMSE>CPER_2010/_/MSEMSE.2	4	2561
FC/MSEMSE>CPER_2010/_/MSEMSE.4	1	1211
FC/MSEMSE>CPER_2011/_/MSEMSE.2	2	1280
FC/MSEMSE>CPER_2012/_/MSEMSE.2	1	640
FC/MSEMSE>CPER_2013/_/MSEMSE.2	1	640
FC/MSEMSE>CPER_2014/_/MSEMSE.2	1	640
FC/MSEMSE>CPER_2014/_/MSEMSE.4	2	2422
FC/MSEMSE>CPER_2015/_/MSEMSE.2	2	1280
FC/MSEMSE>CPER_2015/_/MSEMSE.4	1	1211
FC/MSEMSE>CPER_2016/_/MSEMSE.2	1	640
FC/MSEMSE>CPER_2017/_/MSEMSE.2	2	1280
FC/MSEMSE>CPER_2018/_/MSEMSE.2	2	1280
FC/MSEMSE>CPER_2019/_/MSEMSE.2	1	640
FC/MSEMNW>CANN_2002/_/MSEMNW.2	1	618
FC/MSEMNW>CANN_2007/_/MSEMNW.2	2	1236
FC/MSEMNW>CANN_2008/_/MSEMNW.2	3	1854
FC/MSEMNW>CANN_2011/_/MSEMNW.2	1	618
FC/MSEMNW>CANN_2012/_/MSEMNW.2	2	1236
FC/MSEMNW>CANN_2013/_/MSEMNW.2	3	1854
FC/MSEMNW>CANN_2013/_/MSEMNW.4	1	1213
FC/MSEMNW>CANN_2014/_/MSEMNW.2	4	2472
FC/MSEMNW>CANN_2015/_/MSEMNW.2	2	1236
FC/MSEMNW>CANN_2015/_/MSEMNW.4	1	1213
FC/MSEMNW>CANN_2016/_/MSEMNW.2	3	1854
FC/MSEMNW>CANN_2016/_/MSEMNW.4	1	1213
FC/MSEMNW>CANN_2017/_/MSEMNW.2	4	2472
FC/MSEMNW>CANN_2018/_/MSEMNW.2	1	618
FC/MSEMNW>CANN_2019/_/MSEMNW.2	1	618
FC/MSEMNW>CPER_2003/_/MSEMNW.2	1	618
FC/MSEMNW>CPER_2005/_/MSEMNW.2	2	1236
FC/MSEMNW>CPER_2006/_/MSEMNW.2	1	618
FC/MSEMNW>CPER_2009/_/MSEMNW.2	1	618
FC/MSEMNW>CPER_2009/_/MSEMNW.4	1	1213
FC/MSEMNW>CPER_2010/_/MSEMNW.2	1	618
FC/MSEMNW>CPER_2011/_/MSEMNW.2	4	2472
FC/MSEMNW>CPER_2011/_/MSEMNW.4	5	6064
FC/MSEMNW>CPER_2012/_/MSEMNW.2	2	1236
FC/MSEMNW>CPER_2013/_/MSEMNW.2	2	1236
FC/MSEMNW>CPER_2014/_/MSEMNW.2	1	618
FC/MSEMNW>CPER_2014/_/MSEMNW.4	1	1213
FC/MSEMNW>CPER_2015/_/MSEMNW.2	4	2472
FC/UPEVER>CANN_2012/_/UPEVER.1	1	159
FC/UPEVER>CANN_2013/_/UPEVER.1	3	478
FC/UPEVER>CANN_2016/_/UPEVER.1	1	159
FC/UPEVER>CANN_2017/_/UPEVER.1	1	159

FC/UPEVER>CPER_2006/_/UPEVER.1	1	159
FC/UPEVER>CPER_2011/_/UPEVER.1	1	159
FC/UPEVER>CPER_2015/_/UPEVER.1	1	159
FC/UPEVER>CPER_2016/_/UPEVER.1	2	319
FC/UPEVER>CPER_2017/_/UPEVER.1	1	159
FC/DRYFIRE>CANN_2016/_/DRYFIRE.8	1	6594
FC/DRYFIRE>CANN_2018/_/DRYFIRE.8	1	6594
FC/DRYINNER>CANN_2017/_/DRYINNER.8	2	13188
FC/SAV>CANN_2001/_/SAV.8	2	13188
FC/SAV>CANN_2004/_/SAV.8	1	6594
FC/SAV>CANN_2007/_/SAV.8	1	6594
FC/SAV>CANN_2009/_/SAV.8	2	13188
FC/SAV>CANN_2010/_/SAV.8	2	13188
FC/SAV>CANN_2011/_/SAV.8	6	39563
FC/SAV>CANN_2012/_/SAV.8	1	6594
FC/SAV>CANN_2013/_/SAV.8	1	6594
FC/SAV>CANN_2014/_/SAV.8	1	6594
FC/SAV>CANN_2015/_/SAV.8	1	6594
FC/SAV>CANN_2016/_/SAV.8	4	26375
FC/SAV>CANN_2017/_/SAV.8	1	6594
FC/SAV>CANN_2018/_/SAV.8	1	6594
FC/SOUTH>CANN_2015/_/SOUTH.8	1	6594
GC/GRASS>CANN_2002/_/SAV.8	1	6594
GC/GRASS>CANN_2003/_/MSEMNW.2	1	618
GC/GRASS>CANN_2009/_/SAV.8	3	19781
GC/GRASS>CANN_2010/_/DRYINNER.8	1	6594
GC/GRASS>CANN_2011/_/SAV.8	1	6594
GC/GRASS>CANN_2011/_/SOUTH.8	1	6594
GC/GRASS>CANN_2012/_/DRYFIRE.8	1	6594
GC/GRASS>CANN_2013/_/SAV.8	3	19781
GC/GRASS>CANN_2014/_/DRYINNER.8	1	6594
GC/GRASS>CANN_2014/_/MSEMSE.2	1	640
GC/GRASS>CANN_2014/_/WETEVER.4	1	1212
GC/GRASS>CANN_2017/_/DRYFIRE.8	1	6594
GC/GRASS>CPER_2003/_/MSEMSE.2	1	640
GC/GRASS>CPER_2012/_/MSEMSE.2	1	640
GC/GRASS>CPER_2013/_/DRYFIRE.8	1	6594
GC/GRASS>CPER_2014/_/MSEMSE.2	1	640
WC/WET>CANN_2012/_/MSEMSE.2	1	640
WC/WET>CANN_2013/_/DRYINNER.8	1	6594
SC/SET>CANN_2014/_/MSEMSE.2	1	640
SC/SET>CANN_2018/_/SOUTH.8	1	6594
OC/OTHER>CANN_2009/_/MSEMNW.4	1	1213
OC/OTHER>CANN_2011/_/SAV.8	1	6594
OC/OTHER>CANN_2012/_/MSEMNW.2	1	618
OC/OTHER>CPER_2009/_/MSEMSE.2	1	640
OC/OTHER>CPER_2013/_/MSEMNW.2	1	618

Table 16. Pivot table information for Grassland.

GRASSLANDS		
Total Sum	737	4,131,706
Row Labels	Count of Transition Coding	Area [Ha]
GG/GRASS/_/DRYFIRE.8	21	138469
GG/GRASS/_/DRYINNER.8	7	46156

GG/GRASS/_/MEVER.2	12	7641
GG/GRASS/_/MEVER.4	8	10166
GG/GRASS/_/MSEMNW.2	12	7415
GG/GRASS/_/MSEMNW.4	11	13341
GG/GRASS/_/MSEMSE.2	23	14723
GG/GRASS/_/MSEMSE.4	15	18163
GG/GRASS/_/SAV.8	550	3626574
GG/GRASS/_/SOUTH.8	2	13188
GG/GRASS/_/UPEVER.1	3	478
GG/GRASS/_/WETEVER.2	4	2425
GG/GRASS/_/WETEVER.4	1	1212
GG/GRASS/fire_2004/SAV.8	1	6594
GG/GRASS/fire_2006/SAV.8	1	6594
GG/GRASS/fire_2011/SAV.8	1	6594
GG/GRASS/fire_2012/SAV.8	1	6594
GG/GRASS/fire_2013/MSEMSE.2	1	640
GG/GRASS/fire_2013/SAV.8	3	19781
GG/GRASS/fire_2014/SAV.8	1	6594
GG/GRASS/fire_2015/MSEMSE.2	1	640
GG/GRASS/fire_2016/SAV.8	4	26375
GG/GRASS/fire_2017/SAV.8	2	13188
FG/WETEVER>GRASS_2015/Dist_2017/WETEVER.2	1	606
FG/MEVER>GRASS_2011/Dist_2019/MEVER.2	1	637
FG/MEVER>GRASS_2016/fire_2014/MEVER.2	1	637
FG/MSEMSE>GRASS_2006/_/MSEMSE.2	2	1280
FG/MSEMSE>GRASS_2010/logging_2005/MSEMSE.4	1	1211
FG/MSEMSE>GRASS_2010/logging_2010/MSEMSE.2	1	640
FG/MSEMSE>GRASS_2016/_/MSEMSE.4	1	1211
FG/MSEMSE>GRASS_2017/logging_/MSEMSE.2	1	640
FG/MSEMNW>GRASS_2010/_/MSEMNW.4	1	1213
FG/MSEMNW>GRASS_2018/_/MSEMNW.4	1	1213
FG/UPEVER>GRASS_2011/logging_2011/UPEVER.1	1	159
FG/UPEVER>GRASS_2015/_/UPEVER.1	1	159
FG/UPEVER>GRASS_2015/logging_2017/UPEVER.1	1	159
FG/UPEVER>GRASS_2018/_/UPEVER.1	1	159
FG/SAV>GRASS_2002/_/SAV.8	1	6594
FG/SAV>GRASS_2005/_/SAV.8	1	6594
FG/SAV>GRASS_2014/_/SAV.8	1	6594
FG/SAV>GRASS_2014/Dist_2018/SAV.8	1	6594
FG/SAV>GRASS_2016/_/SAV.8	1	6594
CG/CANN>GRASS_2001/_/SAV.8	1	6594
CG/CANN>GRASS_2005/_/SAV.8	1	6594
CG/CANN>GRASS_2009/_/SAV.8	2	13188
CG/CANN>GRASS_2010/_/MSEMSE.2	1	640
CG/CANN>GRASS_2011/_/MSEMSE.2	1	640
CG/CANN>GRASS_2012/_/SAV.8	1	6594
CG/CANN>GRASS_2013/_/MSEMNW.4	1	1213
CG/CANN>GRASS_2014/_/MSEMSE.2	1	640
CG/CANN>GRASS_2014/_/SAV.8	1	6594
CG/CANN>GRASS_2015/_/DRYINNER.8	1	6594
CG/CANN>GRASS_2015/_/MSEMNW.4	1	1213
CG/CANN>GRASS_2016/_/MSEMNW.2	1	618
CG/CANN>GRASS_2016/_/SAV.8	3	19781
CG/CANN>GRASS_2018/_/MSEMNW.2	1	618
CG/CANN>GRASS_2018/_/MSEMSE.2	1	640
CG/CANN>GRASS_2019/_/MSEMNW.2	1	618
CG/CFA>GRASS_2007/_/MSEMNW.2	1	618
CG/CPER>GRASS_2013/fire_2011/MSEMSE.4	1	1211

CG/CPER>GRASS_2014/_/MSEMSE.2	3	1920
CG/CPER>GRASS_2015/_/MSEMNW.4	1	1213
CG/CPER>GRASS_2015/_/MSEMSE.2	1	640
CG/CPER>GRASS_2015/_/MSEMSE.4	1	1211
CG/CPER>GRASS_2015/_/WETEVER.4	1	1212
CG/CPER>GRASS_2018/_/MEVER.2	1	637
CG/CPER>GRASS_2019/_/SAV.8	1	6594
SG/SET>GRASS_2010/fire_2010/SAV.8	1	6594
OG/OTHER>GRASS_2003/_/MSEMSE.2	1	640

Table 17. Pivot table information for Wetlands.

WETLANDS		
Total Sum	125	767,613
Row Labels	Count of Transition Coding	Area [Ha]
WW/WET/_/DRYFIRE.8	5	32969
WW/WET/_/DRYINNER.8	1	6594
WW/WET/_/MEVER.4	1	1271
WW/WET/_/MSEMNW.2	2	1236
WW/WET/_/MSEMNW.4	1	1213
WW/WET/_/MSEMSE.4	3	3633
WW/WET/_/SAV.8	107	705534
WW/WET/_/WETEVER.2	1	606
WW/WET/_/WETEVER.4	1	1212
WW/WET/_/WETEVER.8	1	6594
CW/CPER>WET_2015/_/UPEVER.1	1	159
GW/GRASS>WET_2014/_/SAV.8	1	6594

Table 18. Pivot table information for Settlements.

SETTLEMENTS		
Total Sum	**311**	**788,693**
Row Labels	**Count of Transition Coding**	**Area [Ha]**
SS/SET/_/DRYFIRE.8	2	13188
SS/SET/_/DRYINNER.8	10	65938
SS/SET/_/MEVER.2	5	3184
SS/SET/_/MEVER.4	17	21602
SS/SET/_/MSEMNW.2	5	3090
SS/SET/_/MSEMNW.4	38	46088
SS/SET/_/MSEMSE.2	10	6401
SS/SET/_/MSEMSE.4	44	53279
SS/SET/_/SAV.8	51	336282
SS/SET/_/SOUTH.8	7	46156
SS/SET/_/UPEVER.1	10	1593
SS/SET/_/WETEVER.2	4	2425
SS/SET/_/WETEVER.4	3	3636
FS/MSEMSE>SET_2012/_/MSEMSE.2	1	640
FS/MSEMSE>SET_2013/_/MSEMSE.2	1	640
FS/MSEMSE>SET_2015/_/MSEMSE.2	1	640
FS/UPEVER>SET_2007/_/UPEVER.1	1	159
FS/UPEVER>SET_2009/_/UPEVER.1	1	159
FS/UPEVER>SET_2013/_/UPEVER.1	1	159
FS/SAV>SET_2014/_/SAV.8	1	6594

FS/SOUTH>SET_2004/_/SOUTH.8	1	6594
FS/WETEVER>SET_2005/_/WETEVER.4	1	1212
FS/MEVER>SET_2011/_/MEVER.4	2	2541
FS/MEVER>SET_2012/_/MEVER.2	1	637
FS/MEVER>SET_2014/_/MEVER.4	1	1271
FS/MEVER>SET_2015/_/MEVER.2	1	637
FS/MEVER>SET_2017/_/MEVER.2	2	1273
FS/MEVER>SET_2018/_/MEVER.4	1	1271
CS/CANN>SET_2005/_/MSEMSE.4	1	1211
CS/CANN>SET_2009/_/MSEMSE.2	1	640
CS/CANN>SET_2011/_/MEVER.4	1	1271
CS/CANN>SET_2011/_/MSEMNW.2	2	1236
CS/CANN>SET_2011/_/MSEMNW.4	1	1213
CS/CANN>SET_2011/_/MSEMSE.2	1	640
CS/CANN>SET_2011/_/MSEMSE.4	1	1211
CS/CANN>SET_2011/_/SAV.8	1	6594
CS/CANN>SET_2012/_/DRYINNER.8	1	6594
CS/CANN>SET_2012/_/SAV.8	1	6594
CS/CANN>SET_2013/_/MEVER.2	1	637
CS/CANN>SET_2013/_/MEVER.4	2	2541
CS/CANN>SET_2013/_/MSEMNW.4	3	3639
CS/CANN>SET_2013/_/MSEMSE.4	2	2422
CS/CANN>SET_2013/_/SOUTH.8	1	6594
CS/CANN>SET_2014/_/MSEMNW.4	1	1213
CS/CANN>SET_2014/_/MSEMSE.4	1	1211
CS/CANN>SET_2014/_/SAV.8	1	6594
CS/CANN>SET_2015/_/MEVER.2	1	637
CS/CANN>SET_2015/_/MSEMNW.4	2	2426
CS/CANN>SET_2015/_/MSEMSE.2	1	640
CS/CANN>SET_2015/_/MSEMSE.4	2	2422
CS/CANN>SET_2015/_/UPEVER.1	2	319
CS/CANN>SET_2017/_/MEVER.4	1	1271
CS/CANN>SET_2017/_/MSEMNW.4	1	1213
CS/CANN>SET_2017/_/SOUTH.8	1	6594
CS/CANN>SET_2017/_/WETEVER.2	1	606
CS/CANN>SET_2018/_/MSEMNW.2	1	618
CS/CANN>SET_2018/_/MSEMSE.4	1	1211
CS/CANN>SET_2018/_/UPEVER.1	1	159
CS/CANN>SET_2019/_/MSEMNW.2	1	618
CS/CANN>SET_2019/_/MSEMSE.2	1	640
CS/CFA>SET_/_/SAV.8	1	6594
CS/CPER>SET_2006/_/MSEMNW.4	1	1213
CS/CPER>SET_2007/_/MSEMNW.2	1	618
CS/CPER>SET_2008/_/MSEMNW.2	1	618
CS/CPER>SET_2011/_/UPEVER.1	1	159
CS/CPER>SET_2013/_/MEVER.4	3	3812
CS/CPER>SET_2013/_/MSEMNW.2	1	618
CS/CPER>SET_2013/_/MSEMSE.2	2	1280
CS/CPER>SET_2013/_/MSEMSE.4	1	1211
CS/CPER>SET_2013/_/WETEVER.2	1	606
CS/CPER>SET_2013/_/WETEVER.4	1	1212
CS/CPER>SET_2014/_/MEVER.4	1	1271
CS/CPER>SET_2014/_/MSEMSE.4	2	2422
CS/CPER>SET_2014/_/UPEVER.1	2	319
CS/CPER>SET_2015/_/MEVER.2	1	637
CS/CPER>SET_2015/_/MEVER.4	3	3812
CS/CPER>SET_2015/_/MSEMNW.4	2	2426
CS/CPER>SET_2017/_/MEVER.4	2	2541

CS/CPER>SET_2018/_/MSEMSE.4	1	1211
CS/CPER>SET_2019/_/MEVER.2	1	637
CS/CPER>SET_2019/_/UPEVER.1	1	159
GS/GRASS>SET_2003/_/MSEMNW.2	1	618
GS/GRASS>SET_2004/_/SAV.8	1	6594
GS/GRASS>SET_2006/_/SAV.8	1	6594
GS/GRASS>SET_2010/_/DRYFIRE.8	1	6594
GS/GRASS>SET_2011/_/MSEMNW.2	1	618
GS/GRASS>SET_2011/_/MSEMSE.4	2	2422
GS/GRASS>SET_2011/_/SAV.8	2	13188
GS/GRASS>SET_2011/_/WETEVER.2	1	606
GS/GRASS>SET_2012/_/MSEMNW.4	1	1213
GS/GRASS>SET_2013/_/SAV.8	1	6594
GS/GRASS>SET_2014/_/MSEMSE.4	1	1211
GS/GRASS>SET_2014/_/SOUTH.8	1	6594
GS/GRASS>SET_2015/_/MSEMSE.4	1	1211
WS/WET>SET_2014/_/MEVER.4	1	1271
WS/WET>SET_2018/_/MSEMSE.2	1	640
OS/OTHER>SET_2019/_/MEVER.2	1	637

Table 19.Pivot table information for Other Land.

OTHER LAND		
Total Sum	63	113,874
Row Labels	Count of Transition Coding	Area [Ha]
OO/OTHER/_/DRYINNER.8	1	6594
OO/OTHER/_/MEVER.2	3	1910
OO/OTHER/_/MEVER.4	4	5083
OO/OTHER/_/MSEMNW.2	14	8651
OO/OTHER/_/MSEMNW.4	3	3639
OO/OTHER/_/MSEMSE.2	9	5761
OO/OTHER/_/MSEMSE.4	6	7265
OO/OTHER/_/SAV.8	8	52750
OO/OTHER/_/UPEVER.1	1	159
OO/OTHER/_/WETEVER.2	1	606
OO/OTHER/_/WETEVER.4	2	2424
FO/MEVER>OTHER_2015/_/MEVER.4	1	1271
FO/MSEMSE>OTHER_2013/_/MSEMSE.2	1	640
FO/MSEMSE>OTHER_2014/_/MSEMSE.2	2	1280
FO/MSEMNW>OTHER_2007/_/MSEMNW.2	1	618
FO/MSEMNW>OTHER_2014/_/MSEMNW.2	1	618
FO/UPEVER>OTHER_2007/_/UPEVER.1	1	159
CO/CANN>OTHER_2002/_/SAV.8	1	6594
CO/CANN>OTHER_2010/_/SAV.8	1	6594
CO/CANN>OTHER_2016/_/MSEMNW.2	1	618
CO/CFA>OTHER_2018/_/MSEMSE.2	1	640

Even though the land use and land-use changes matrices are not used *per se* for the calculations, they are nonetheless provided below for each change period from 2000-2001 until 2014-2015. For the purpose of reconstruction of the FREL/FRL, the coding system and pivot table must be used. These LULUC matrices include the areas of land remaining in the same land-use category (diagonal values) and areas of land converted to and from a given land-use category (off-diagonal values). For the purposes of the REDD+ activities selected in this submission, only the forest-related information in the matrices is relevant.

LAND USE CHANGES

Period	Land Use and Land Use Change (LULUC) Vertical: Final Use Horizontal: Initial Use	Wet Evergreen Forest	Moist Evergreen Forest	Moist Semi-deciduous SE Forest	Moist Semi-deciduous NW Forest	Upland Evergreen Forest	Dry Semidecidouos (Fire Zone) Forest	Dry Semidecidouos (Inner Zone) Forest	Savannah Forest	Southern Marginal Forest	Croplands, Annual Crops	Croplands, Perennial Crops	Croplands, Fallow	Grasslands (Pasture / Savannahs / Shrublands)	Wetland	Settlement	Other Lands	TOTAL
2014-2015	Wet Evergreen Forest	279,515											606	606				
	Moist Evergreen Forest		620,574								1,273	1,273				637	1271	
	Moist Semi-deciduous SE Forest			383,137								2,491				640		
	Moist Semi-deciduous NW Forest				421,867						2,449	2,472						
	Upland Evergreen Forest					30,902						159		319				
	Dry Semidecidouos (Fire Zone) Forest						513,034											
	Dry Semidecidouos (Inner Zone) Forest							303,313										
	Savannah Forest								2,888,072		6,594							
	Southern Marginal Forest									46,156	6,594							
	Croplands, Annual Crops		1271		618		6594	6594			8423175			7807		6443		
	Croplands, Perennial Crops											4006732		4276	159	6875		
	Croplands, Fallow												204818					
	Grasslands (Pasture / Savannahs / Shrublands)								6594					4,092,567		1211		
	Wetland														768,094			
	Settlement															744,995		
	Other Lands																112,645	
	TOTAL	279,515	621,845	383,137	422,485	30,902	519,628	309,907	2,894,666	46,156	8,440,085	4,013,128	205,424	4,105,575	768,254	760,800	113,915	23,915,421
									21,670	5,508,240			12,658,637	4,105,575	768,254			0
2013-2014	Wet Evergreen Forest	280,727										606						
	Moist Evergreen Forest		625,029								1,271	4,449	1,271			1271		
	Moist Semi-deciduous SE Forest			383,777							2,422	3,062	640				1280	
	Moist Semi-deciduous NW Forest				426,169						2,472	1,831					618	
	Upland Evergreen Forest					31,380												
	Dry Semidecidouos (Fire Zone) Forest						506,440										1280	
	Dry Semidecidouos (Inner Zone) Forest							303,313										
	Savannah Forest								2,888,072		6,594			13188		6594		
	Southern Marginal Forest									52,750								
	Croplands, Annual Crops			1851			6594				8430657			7234		9017		
	Croplands, Perennial Crops			640								4007454		1920		4011		
	Croplands, Fallow												202907					
	Grasslands (Pasture / Savannahs / Shrublands)								6594		8446	640		4,078,030	6594	7805		
	Wetland														761,501	1271		
	Settlement										640					715,026		
	Other Lands				618												109,466	
	TOTAL	280,727	625,029	386,268	426,787	31,380	513,034	303,313	2,894,666	52,750	8,452,501	4,018,042	204,818	4,100,372	768,094	744,995	112,645	23,915,421
									16,297	5,513,955			12,675,361	4,100,372	768,094			0
2012-2013	Wet Evergreen Forest	281,334									1,212	1,213						
	Moist Evergreen Forest		632,019								1,271	5,086						
	Moist Semi-deciduous SE Forest			390,541							640	640	1,211			640	640	
	Moist Semi-deciduous NW Forest				431,090						3,067	1,236						
	Upland Evergreen Forest					31,380					478					159		
	Dry Semidecidouos (Fire Zone) Forest						507,720											
	Dry Semidecidouos (Inner Zone) Forest							303,313										
	Savannah Forest								2,901,259		6,594							
	Southern Marginal Forest									52,750								
	Croplands, Annual Crops			640							8415717			1213		15832		
	Croplands, Perennial Crops											3998640		1211		8740		
	Croplands, Fallow												201696					
	Grasslands (Pasture / Savannahs / Shrublands)								13188		19781	6594		4,105,684				
	Wetland										6594				762,771			
	Settlement		1271													690,295		
	Other Lands											618					109,444	
	TOTAL	281,334	633,290	391,181	431,090	31,380	507,720	303,313	2,914,447	52,750	8,455,353	4,014,026	202,907	4,108,108	762,771	715,666	110,084	23,915,421
									15,098	5,546,505			12,672,286	4,108,108	762,771			0
2011-2012	Wet Evergreen Forest	283,758																
	Moist Evergreen Forest		637,739										637			637		
	Moist Semi-deciduous SE Forest			394,312							4,412	640				640		
	Moist Semi-deciduous NW Forest				435,392						1,236	1,236						
	Upland Evergreen Forest					32,017					159							
	Dry Semidecidouos (Fire Zone) Forest						507,720											
	Dry Semidecidouos (Inner Zone) Forest							303,313										
	Savannah Forest								2,894,666		6,594							
	Southern Marginal Forest									52,750								
	Croplands, Annual Crops		637						6594		8413150			6594		13188		
	Croplands, Perennial Crops											4006074						
	Croplands, Fallow												201059					
	Grasslands (Pasture / Savannahs / Shrublands)								6594		6594	640		4,138,653		1213		
	Wetland										640				769,365			
	Settlement															675,889		
	Other Lands										618						110,062	
	TOTAL	283,758	638,375	394,312	435,392	32,017	507,720	303,313	2,907,853	52,750	8,433,402	4,008,590	201,696	4,145,247	769,365	691,566	110,062	23,915,421
									13,824	5,555,492			12,643,689	4,145,247	769,365			0

2010-2011

Wet Evergreen Forest	283,758																
Moist Evergreen Forest		639,012									1,271		637		2541		
Moist Semi-deciduous SE Forest			400,004							1,920	1,280						
Moist Semi-deciduous NW Forest				437,246						618	8,536						
Upland Evergreen Forest					32,177						159		159				
Dry Semidecidouos (Fire Zone) Forest						507,720											
Dry Semidecidouos (Inner Zone) Forest							303,313										
Savannah Forest								2,894,666		39,563							
Southern Marginal Forest									52,750								
Croplands, Annual Crops								6594		8378279			640		12164		
Croplands, Perennial Crops											3994828				159		
Croplands, Fallow												201059					
Grasslands (Pasture / Savannahs / Shrublands)				618						13188			4,152,258		16834		
Wetland														770,005			
Settlement															644,190		
Other Lands										6594						110,680	
TOTAL	283,758	639,012	400,004	437,864	32,177	507,720	303,313	2,901,259	52,750	8,440,162	4,006,074	201,059	4,153,694	770,005	675,889	110,680	23,915,421
								7,212	5,557,858			12,647,295	4,153,694	770,005			0

2009-2010

Wet Evergreen Forest	283,758										606						
Moist Evergreen Forest		643,461															
Moist Semi-deciduous SE Forest			402,565								3,771		1851				
Moist Semi-deciduous NW Forest				446,399							618		1213				
Upland Evergreen Forest					32,495												
Dry Semidecidouos (Fire Zone) Forest						507,720											
Dry Semidecidouos (Inner Zone) Forest							303,313										
Savannah Forest								2,934,228		13,188							
Southern Marginal Forest									52,750								
Croplands, Annual Crops			640							8377896			640			6594	
Croplands, Perennial Crops											3989992						
Croplands, Fallow												201059					
Grasslands (Pasture / Savannahs / Shrublands)										6594			4,172,599		6594		
Wetland														770,005			
Settlement													6594		637,596		
Other Lands																110,680	
TOTAL	283,758	643,461	403,205	446,399	32,495	507,720	303,313	2,934,228	52,750	8,397,678	3,994,987	201,059	4,182,897	770,005	644,190	117,274	23,915,421
								640	5,607,331			12,593,724	4,182,897	770,005			0

2008-2009

Wet Evergreen Forest	284,365																
Moist Evergreen Forest		643,461								1,271							
Moist Semi-deciduous SE Forest			406,976							640							
Moist Semi-deciduous NW Forest				448,230							1,831						
Upland Evergreen Forest					32,495										159		
Dry Semidecidouos (Fire Zone) Forest						507,720											
Dry Semidecidouos (Inner Zone) Forest							303,313										
Savannah Forest								2,940,822		13,188							
Southern Marginal Forest									52,750								
Croplands, Annual Crops								6594		8349678			13188		640		
Croplands, Perennial Crops			1211								3987521						
Croplands, Fallow												201059					
Grasslands (Pasture / Savannahs / Shrublands)										19781			4,172,599				
Wetland														770,005			
Settlement															643,391		
Other Lands										1213	640					110,680	
TOTAL	284,365	643,461	408,187	448,230	32,495	507,720	303,313	2,947,416	52,750	8,385,770	3,989,992	201,059	4,185,786	770,005	644,190	110,680	23,915,421
								7,805	5,627,938			12,576,821	4,185,786	770,005			0

2007-2008

Wet Evergreen Forest	284,365																
Moist Evergreen Forest		644,095									1,271						
Moist Semi-deciduous SE Forest			407,616								640						
Moist Semi-deciduous NW Forest				450,061						1,854							
Upland Evergreen Forest					32,654												
Dry Semidecidouos (Fire Zone) Forest						507,720											
Dry Semidecidouos (Inner Zone) Forest							303,313										
Savannah Forest								2,954,010									
Southern Marginal Forest									52,750								
Croplands, Annual Crops										8368245							
Croplands, Perennial Crops		637									3986821				618		
Croplands, Fallow												201059					
Grasslands (Pasture / Savannahs / Shrublands)													4,192,380				
Wetland														770,005			
Settlement															642,773		
Other Lands																112,533	
TOTAL	284,365	644,732	407,616	450,061	32,654	507,720	303,313	2,954,010	52,750	8,370,099	3,988,732	201,059	4,192,380	770,005	643,391	112,533	23,915,421
									5,637,222			12,559,890	4,192,380	770,005			0

2006-2007

Wet Evergreen Forest	284,365																
Moist Evergreen Forest		645,366									1,271						
Moist Semi-deciduous SE Forest			408,256								640						
Moist Semi-deciduous NW Forest				451,915						1,236						0	
Upland Evergreen Forest					32,654										159	159	
Dry Semidecidouos (Fire Zone) Forest						507,720											
Dry Semidecidouos (Inner Zone) Forest							303,313										
Savannah Forest								2,954,010		6,594							
Southern Marginal Forest									52,750								
Croplands, Annual Crops										8360416							
Croplands, Perennial Crops											3986164				618		
Croplands, Fallow												201059	618				
Grasslands (Pasture / Savannahs / Shrublands)													4,191,762				
Wetland														770,005			
Settlement															641,996		
Other Lands																112,374	
TOTAL	284,365	645,366	408,256	451,915	32,654	507,720	303,313	2,954,010	52,750	8,368,245	3,988,075	201,059	4,192,380	770,005	642,773	112,533	23,915,421
									5,640,350			12,557,380	4,192,380	770,005			0

2005-2006

Wet Evergreen Forest	284,365																
Moist Evergreen Forest		646,636									637						
Moist Semi-deciduous SE Forest			408,897							640	1,280		1280				
Moist Semi-deciduous NW Forest				453,150							618						
Upland Evergreen Forest					32,973						159						
Dry Semidecidouos (Fire Zone) Forest						507,720											
Dry Semidecidouos (Inner Zone) Forest							303,313										
Savannah Forest								2,960,603									
Southern Marginal Forest									52,750								
Croplands, Annual Crops										8359776							
Croplands, Perennial Crops											3984088				1213		
Croplands, Fallow												201677					
Grasslands (Pasture / Savannahs / Shrublands)													4,190,482		6594		
Wetland														770,005			
Settlement															634,189		
Other Lands																112,374	
TOTAL	284,365	646,636	408,897	453,150	32,973	507,720	303,313	2,960,603	52,750	8,360,416	3,986,782	201,677	4,191,762	770,005	641,996	112,374	23,915,421
								0	5,650,409			12,548,876	4,191,762	770,005			0

2004-2005

Wet Evergreen Forest	284,365														1212		
Moist Evergreen Forest		647,273															
Moist Semi-deciduous SE Forest			412,097														
Moist Semi-deciduous NW Forest				453,768							1,236						
Upland Evergreen Forest					33,132												
Dry Semidecidouos (Fire Zone) Forest						507,720											
Dry Semidecidouos (Inner Zone) Forest							303,313										
Savannah Forest								2,960,603					6594				
Southern Marginal Forest									52,750								
Croplands, Annual Crops										8359776			6594		1211		
Croplands, Perennial Crops											3984065						
Croplands, Fallow												201677					
Grasslands (Pasture / Savannahs / Shrublands)													4,183,888				
Wetland														770,005			
Settlement															631,766		
Other Lands																112,374	
TOTAL	284,365	647,273	412,097	453,768	33,132	507,720	303,313	2,960,603	52,750	8,359,776	3,985,301	201,677	4,197,076	770,005	634,189	112,374	23,915,421
								0	5,655,023			12,546,754	4,197,076	770,005			0

2003-2004

Wet Evergreen Forest	285,577																
Moist Evergreen Forest		647,273									637						
Moist Semi-deciduous SE Forest			412,097														
Moist Semi-deciduous NW Forest				455,004													
Upland Evergreen Forest					33,132												
Dry Semidecidouos (Fire Zone) Forest						507,720											
Dry Semidecidouos (Inner Zone) Forest							303,313										
Savannah Forest								2,967,197		6,594							
Southern Marginal Forest									52,750						6594		
Croplands, Annual Crops										8360987							
Croplands, Perennial Crops											3983428						
												201677					
Grasslands (Pasture / Savannahs / Shrublands)													4,183,888		6594		
Wetland														770,005			
Settlement															618,578		
Other Lands																112,374	
TOTAL	285,577	647,273	412,097	455,004	33,132	507,720	303,313	2,967,197	52,750	8,367,580	3,984,065	201,677	4,183,888	770,005	631,766	112,374	23,915,421
								0	5,664,065			12,553,323	4,183,888	770,005			0

2002-2003

Wet Evergreen Forest	285,577																
Moist Evergreen Forest		647,910															
Moist Semi-deciduous SE Forest			412,097							640	640						
Moist Semi-deciduous NW Forest				455,004							618						
Upland Evergreen Forest					33,132												
Dry Semidecidouos (Fire Zone) Forest						507,720											
Dry Semidecidouos (Inner Zone) Forest							303,313										
Savannah Forest								2,973,791									
Southern Marginal Forest									59,344								
Croplands, Annual Crops										8359729							
Croplands, Perennial Crops											3981530						
Croplands, Fallow												201677					
Grasslands (Pasture / Savannahs / Shrublands)										618	640		4,189,842		618		
Wetland														770,005			
Settlement															617,961		
Other Lands													640			112,374	
TOTAL	285,577	647,910	412,097	455,004	33,132	507,720	303,313	2,973,791	59,344	8,360,987	3,983,428	201,677	4,190,482	770,005	618,578	112,374	23,915,421
									5,677,889			12,546,092	4,190,482	770,005			0

2001-2002

Wet Evergreen Forest	285,577																
Moist Evergreen Forest		647,910															
Moist Semi-deciduous SE Forest			413,378								640						
Moist Semi-deciduous NW Forest				455,622						618							
Upland Evergreen Forest					33,132												
Dry Semidecidouos (Fire Zone) Forest						507,720											
Dry Semidecidouos (Inner Zone) Forest							303,313										
Savannah Forest								2,973,791					6594				
Southern Marginal Forest									59,344								
Croplands, Annual Crops										8352517						6594	
Croplands, Perennial Crops											3980890						
Croplands, Fallow												201677					
Grasslands (Pasture / Savannahs / Shrublands)										6594			4,185,124				
Wetland														770,005			
Settlement															617,961		
Other Lands																106,420	
TOTAL	285,577	647,910	413,378	455,622	33,132	507,720	303,313	2,973,791	59,344	8,359,729	3,981,530	201,677	4,191,718	770,005	617,961	113,014	23,915,421
									5,679,788			12,542,936	4,191,718	770,005			0

2000 - 2001

Wet Evergreen Forest	285,577																
Moist Evergreen Forest		647,910															
Moist Semi-deciduous SE Forest			414,018														
Moist Semi-deciduous NW Forest				456,240													
Upland Evergreen Forest					33,132												
Dry Semidecidouos (Fire Zone) Forest						507,720											
Dry Semidecidouos (Inner Zone) Forest							303,313										
Savannah Forest								2,980,385		13,188							
Southern Marginal Forest									59,344								
Croplands, Annual Crops										8345923			6594				
Croplands, Perennial Crops											3980890						
Croplands, Fallow												201677					
Grasslands (Pasture / Savannahs / Shrublands)													4,185,124				
Wetland														770,005			
Settlement															617,961		
Other Lands																106,420	
TOTAL	285,577	647,910	414,018	456,240	33,132	507,720	303,313	2,980,385	59,344	8,359,111	3,980,890	201,677	4,191,718	770,005	617,961	106,420	23,915,421
									5,687,639			12,541,678	4,191,718	770,005			0

2000

Wet Evergreen Forest	285,577																
Moist Evergreen Forest		647,910															
Moist Semi-deciduous SE Forest			414,018														
Moist Semi-deciduous NW Forest				456,240													
Upland Evergreen Forest					33,132												
Dry Semidecidouos (Fire Zone) Forest						507,720											
Dry Semidecidouos (Inner Zone) Forest							303,313										
Savannah Forest								2,993,572									
Southern Marginal Forest									59,344								
Croplands, Annual Crops										8352517							
Croplands, Perennial Crops											3980890						
Croplands, Fallow												201677					
Grasslands (Pasture / Savannahs / Shrublands)													4,185,124				
Wetland														770,005			
Settlement															617,961		
Other Lands																106,420	
TOTAL	285,577	647,910	414,018	456,240	33,132	507,720	303,313	2,993,572	59,344	8,352,517	3,980,890	201,677	4,185,124	770,005	617,961	106,420	23,915,421
									5,700,827			12,535,084	4,185,124	770,005			23,915,421

Average annual increment in biomass (Equation 2.10, Ch2, V4)

Equation 2.9 in the 2006 IPCC GLs requires the estimation of the mean annual biomass growth (G_{TOTAL}), whose calculation is based on equation 2.10 in the 2006 IPCC GLs, reproduced below. G_{TOTAL} is the total biomass growth that expands the aboveground biomass growth (G_W) to include also the belowground biomass growth.

$$G_{TOTAL} = \Sigma \{Gw \bullet (1 + R)\}$$

Where:

G_{TOTAL} = average annual biomass growth above and below-ground, tonnes d. m. ha^{-1} yr^{-1}

Gw = average annual above-ground biomass growth for a specific woody vegetation type, tonnes d. m. ha^{-1} yr^{-1}

R = ratio of below-ground biomass to above-ground biomass for a specific vegetation type, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$

A single value for the average annual above-ground biomass growth has been calculated for each vegetation zone, based on the weighted average of the annual above-ground biomass growth in open and closed forests. For this, the percent distribution of each vegetation zone in open or closed forest was used.

Table 20 provides the weighted average annual above-ground biomass growth for F (Forest Land), C (Cropland) and G (Grassland). The weighted average for Forest Land uses data from Table 27, that provides the percentage distribution of open and closed forest in each vegetation zone; and Table 36, which provides the average above-ground biomass for each vegetation zone in open and closed forests.

As an example of calculation, the value 12.92 t d.m. ha^{-1} yr^{-1} for Wet Evergreen in Table 21 is calculated as follows:

From **Table 27**: % open = 2.78%; % closed = 97.22%

From **Table 36:** above-ground biomass for open forest in Wet Evergreen = 64.40 t d.m. ha^{-1} and 264.02 t d.m. ha^{-1} for closed forests. These values are divided by 20 years (the default value in the IPCC) to provide an estimate of the average annual above-ground biomass for open forest in Wet Evergreen = 64.40/20= 3.22 t d.m. ha^{-1} yr^{-1} and 264.02/20 = 13.20 ha^{-1} yr^{-1} for closed forests.

The weighted average annual above-ground biomass for Wet Evergreen is then: (0.0278 x 3.22 + 0.9722 x 13.20) = 12.92 t d.m. ha^{-1} yr^{-1}.

The summary estimates are provided in Table 21 and details of the calculations presented in Table 22.

Table 20. Weighted average annual above-ground biomass growth for each land-use category and sub-category, in tonnes d.m. ha^{-1} yr^{-1}.

G_W = Weighted Average Annual Above-ground Biomass Growth, tonnes d. m. ha^{-1} yr^{-1}				
LU	Sub-Category	Value	Range / Error	Notes
F	Wet Evergreen	12.92	± 0.25%	AGB/20 years; error range estimated from the standard deviation in Table 4.8 of FPP, converted to t d.m. ha^{-1} divided by 20. CI calculated as $t_{a/2(n-1)}$ x SD/Ön-1. Weights for open and closed forests applied and results divided by the weighted average aboveground biomass. SD = standard deviation; n is sample size.
	Moist Evergreen	14.71	± 0.04%	AGB/20 years; same calculation as indicated for Wet Evergreen.
	Moist Semideciduous SE	12.67	± 0.24%	AGB/20 years; same calculation as indicated for Wet Evergreen.
	Moist Semideciduous NW	4.19	± 0.08%	AGB/20 years; same calculation as indicated for Wet Evergreen.
	Upland Evergreen	7.60	± 0.21%	AGB/20 years; same calculation as indicated for Wet Evergreen.
	Dry Semideciduous (Fire Zone)	1.61	± 1.09%	AGB/20 years; same calculation as indicated for Wet Evergreen.
	Dry Semideciduous (Inner Zone)	2.39	± 0.81%	AGB/20 years; same calculation as indicated for Wet Evergreen.
	Savannah	1.83	± 0.52%	AGB/20 years; same calculation as indicated for Wet Evergreen.
	Southern Marginal	1.11	± 23.16%	AGB/20 years; same calculation as indicated for Wet Evergreen.
C	Annual crops	10	75%	Only one year after conversion
	Perennial crops	5.34	75%	Weighted average by crop: cocoa, oil palm, rubber, other permanent crops.
	Fallow Lands	26.52		Average of the estimates in Adu-Bredu *et al.* (2010)[9].
G	Grassland	22.96		Weighted average by Climate Zones, only one year after conversion. The percentages for the Dry, Moist and Wet zones were derived from the CE samples: 97.2%; 2.5% and 0.2%, respectively.
W	Wetlands	0		Assumed zero
S	Settlements	0		Assumed zero
O	Other lands	0		Assumed zero

[9] Adu-Bredu, S., Abekoe, M., Tachie-Obeng, E., & Tschakert, P. (2010). Carbon stock under four land use systems in three varied ecological zones in Ghana.

8.8 Gw – Forest lands:

Table 21. Above and -below ground biomass for Open and Closed forests in each ecological zone (from Table 36, divided by 20 years) and weighted average annual above-ground biomass growth for each ecological zone (t d.m. ha^{-1} yr_{-1}).

Vegetation Zone	Forest Type	Average Annual Above-ground Biomass Growth (t. d.m. ha^{-1} yr^{-1})	Default / Country Specific	Source
Wet Evergreen (WETVER)	Undisturbed	0.00	CS/ Assumption	Assumed forest has reached maturity and is stable
	Open - Disturbed (Fire, logging, Other Disturbances)	3.22	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % open = 2.78
	Closed - Disturbed (Fire, logging, Other Disturbances)	13.20	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % closed = 97.22
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	12.92		
Moist Evergreen (MEVER)	Undisturbed	0.00	CS/ Assumption	Assumed forest has reached maturity and is stable
	Open - Disturbed (Fire, logging, Other Disturbances)	4.24	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % open = 1.09
	Closed - Disturbed (Fire, logging, Other Disturbances)	14.83	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % closed = 98.91
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	14.71		
Moist Semi-deciduous SE (MSEMSE)	Undisturbed	0.00	CS/ Assumption	Assumed forest has reached maturity and is stable
	Open - Disturbed (Fire, logging, Other Disturbances)	3.74	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % open = 5.00
	Closed - Disturbed (Fire, logging,	13.14	CE / Estimated	Assumed a linear growth of the aboveground biomass in

	Other Disturbances)			20 years after conversion to F; % closed = 95.00
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	12.67		
Moist Semi-deciduous NW (MSEMNW)	Undisturbed	0.00	CS/ Assumption	Assumed forest has reached maturity and is stable
	Open - Disturbed (Fire, logging, Other Disturbances)	1.86	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % open = 4.11
	Closed - Disturbed (Fire, logging, Other Disturbances)	4.29	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % closed = 95.89
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	4.19		
Upland Evergreen (UPEVER)	Undisturbed	0.00	CS/ Assumption	Assumed forest has reached maturity and is stable
	Open - Disturbed (Fire, logging, Other Disturbances)	2.79	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % open = 3.59
	Closed - Disturbed (Fire, logging, Other Disturbances)	7.78	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % closed = 96.41
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	7.60		
Dry Semideciduous (Fire Zone) Forest	Undisturbed	0.00	CS/ Assumption	Assumed forest has reached maturity and is stable
	Open - Disturbed (Fire, logging, Other Disturbances)	1.28	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % open = 3.08
	Closed - Disturbed (Fire, logging, Other Disturbances)	1.62	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % closed = 96.92

	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	1.61		
Dry Semideciduous (Inner Zone) Forest	Undisturbed	0.00	CS/ Assumption	Assumed forest has reached maturity and is stable
	Open - Disturbed (Fire, logging, Other Disturbances)	1.51	CE / Estimated	A Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % open = 8.11
	Closed - Disturbed (Fire, logging, Other Disturbances)	2.47	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % closed = 91.89
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	2.39		
Savannah Forest	Undisturbed	0.00	CS/ Assumption	Assumed forest has reached maturity and is stable
	Open - Disturbed (Fire, logging, Other Disturbances)	1.39	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % open = 12.09
	Closed - Disturbed (Fire, logging, Other Disturbances)	1.89	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % closed = 87.91
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	1.83		
Southern Marginal	Undisturbed	0.00	CS/ Assumption	Assumed forest has reached maturity and is stable
	Open - Disturbed (Fire, logging, Other Disturbances)	0.90	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % open = 28.57
	Closed - Disturbed (Fire, logging, Other Disturbances)	0.19	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F; % closed = 71.43
	Weighted Average - Disturbed (Fire,	1.11		

	logging, Other Disturbances)			

The standard deviation for above-ground biomass ranges from 0.47 – 3.54 t CO_2 ha^{-1}. For Close Forest in Dry Semideciduous Inner Zone, where n=1, the value for Open Forest was duplicated. The same applied when there were no samples collected (e.g., Open Forest in Wet Evergreen; Dry Semideciduous – Fire zone; Closed Forest in Savannah).

8.9 Gw - Croplands:

Gw - Annual Crops:

For annual crops, this submission follows the tier 1 assumption in the 2006 IPCC GLs and assumes that all the aboveground biomass in croplands is reached one year after conversion to Cropland, equal to 5 tC ha^{-1} (or 10 t d.m. ha^{-1}).

Gw - Perennial Crops:

The average annual aboveground biomass growth for perennial crops was estimated from the analysis of results in an extensive assessment of the mainly country-specific published literature. Results were assessed for the major perennial crops in the country: cocoa, oil palm, rubber and other permanent crops such as citrus, cashew and other crop plantations. Some results are provided in Table 23 and the following values were selected:

- For **cocoa**, Ghana used the country-specific estimate for the annual increment in carbon stock in Feurer, M. (2013), equal to **2.5 tC ha^{-1} yr^{-1}**, which is also supported by the finding in Isaac *et al.*, 2007.;
- For **oil palm**, the annual average increment in biomass carbon stocks of **2.0 tC ha^{-1} yr^{-1}** for 23 years old plantation from Kongsager *et al*. (2013), who developed allometric equations to estimate biomass specifically in Ghana, was used. This value is also consistent with that from Feurer, M. (2013);
- For **rubber**, the country-specific estimate of the annual carbon stock increment selected was that from Yang et al. (2005) and Kongsager et al. (2013) (for plantations of 23 and 44 years, respectively), equal to **4.9 tC ha^{-1} yr^{-1}**; this value is consistent with that from Feuer, M. (2013), of 4.63 tC ha^{-1} yr$^{-1;}$
- For **other permanent crops**, such as citrus (3.07 tC ha^{-1} yr^{-1}); yang lang (1.89 tC ha^{-1} yr^{-1}); black pepper (7.53 tC ha^{-1} yr^{-1}); nutmeg (0.956 tC ha^{-1} yr^{-1}) in Feurer. M. (2015). For cashews, the annual average increment is from Benin, which shares boundaries with Ghana, and for which the minimum average increment is 4.2 t tC ha^{-1} yr^{-1} (Daouda *et al*., 2017). So, for permanent crops an average annual increment was estimated as **2.8 tC ha^{-1} yr^{-1}**.

A single estimate of the average annual aboveground biomass growth was developed for Cropland, based on the weighted average of the above estimates for cocoa, oil palm, rubber and other permanent crops and applying the percent share of these perennial crops as estimated from the Collect Earth sample plots, equal to 24.6% for cocoa, 10.7% for oil palm, 1.3% for rubber and 63.4% for other permanent crops.

Thus, the **weighted annual average increment for Cropland** is estimated as: (2.5 tC ha^{-1} yr^{-1} *0,246 + 2.0 *0.107 tC ha^{-1} yr^{-1} + 4.9 * 0.013 tC ha^{-1} yr^{-1} + 2.8 * 0.634 tC ha^{-1} yr^{-1}) = **2.67 tC ha^{-1} yr^{-1}** (or 5.34 t d.m. ha^{-1} yr^{-1}, as indicated in Table 12**).**

Table 22. Some results in the scientific literature assessed (mostly country-specific) on the average annual aboveground growth for specific types of perennial crops.

Type	Age (years)	Annual biomass accumulation rate (tC ha^{-1} yr^{-1})	Error	Default / Country Specific / Other Region	Source
Cocoa	21	3.1		CS	Kongsager *et al.* (2013)[10]
Cocoa	8	2.5		CS	Isaac *et al.* (2007)[11]
Cocoa	30	2.54	15%	CS	Feuer (2013)[12]
Cocoa	8	1.07		CS	Owusu *et al*. (2018)[13]
Cocoa	8	1.29		CS	Isaac *et al*. (2007)
Cocoa	15	1.12		CS	Isaac *et al*. (2005)[14]
Cocoa	20	1.15		CS	Asigbaase *et al*. (2020)[15]
Cocoa	3	4.3		CS	Dawoe (2009)[16]
Oil palm	7	3.1		CS	Kongsager *et al.* (2013)
Oil palm	16	1.8		CS	Kongsager *et al.* (2013)

[10] Kongsager, R.; Napier, J.; Mertz, O. (2013) The carbon sequestration potential of tree crop plantations. Mitig Adapt Strateg Glob Change 18:1197–1213DOI 10.1007/s11027-012-9417-z.

[11] Isaac, M.; Timmer, V.; Quashie-Sam, S. (2007) Shade tree effects in an 8-year-old cocoa agroforestry system: biomass and nutrient diagnosis of *Theobroma* cacao by vector analysis. Nutr Cycl Agroecosyst 78:155–165.

[12] Feuer, M. (2013) Land use systems in Ghana's Central Region and their potential for REDD+. Bachelor Thesis. Bern University of Applied Sciences, School of Agricultural, Forest and Food Sciences, HAFL, Zolliukofen.

[13] Owusu, S.; Anglaaere, L.C.N.; Abugre, S. (2018) Aboveground Biomass and Carbon content of a cocoa – *Gliricida sepium* agroforestry system in Ghana. Ghana Jnl. Agric. Sci. 53, 45 – 60.

[14] Isaac M, Gordon A, Thevathasan N, Oppong S, Quashie-Sam J. (2005) Temporal changes in soil carbon and nitrogen in West African multistrata agroforestry systems: a chronosequence of pools and fluxes. Agrofor Syst. 65(1):23–31

[15] Asigbaase, M.; Dawoe, E.; Lomax, H.; Sjogersten, S. (2020) Biomass and carbon stocks of organic and conventional cocoa agroforestry, Ghana, Agriculture, Ecosystems & Environment, volume 306.

[16] Dawoe, E. (2009) Conversion of natural forest to cocoa agroforest in lowland humid Ghana: impact on plant biomass production, organic carbon and nutrient dynamics. Thesis submitted to the Department of Agroforestry, Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology in partial fulfillment of the requirements for the degree of doctor of philosophy in agroforestry.

Oil palm	23	2.0		CS	Kongsager *et al*. (2013)
Oil palm	25	1.0 – 2.5			Germer and Sauerborn, 2008)[17]
Oil palm	20	2.02	10%	CS	Feuer (2013)
Rubber	12	5.1		CS	Kongsager *et al*. (2013)
Rubber	44	4.9		CS	Kongsager *et al*. (2013)
Rubber	30	9.07			Cheng *et al*., (2007)[18]
Rubber	14	5.45		CS	Wauters *et al*. (2007)[19]
Rubber	23	4.7 - 5.1			Yang et al. (2005)[20]
Rubber		3.5			Saengruksawong *et al*.(2012)[21]
Rubber	30	0.48			Norgrove and Hauser (2013)[22]
Rubber	20	4.63	10%	CS	Feuer (2013)
Orange	25	3.1		CS	Kongsager *et al*. (2013)
Citrus	20	3.07	20%	CS	Feuer (2013)
Cashew	4	2.8	22.4 ± 2.67 t d.m./ha	CS	Biah *et al*. (2018), using CF = 49.05% ± 0.64)[23]
Yang Lang	10	1.89	10%	CS	Feuer (2013)
Black Pepper	8	7.53	10%	CS	Feuer (2013)
Nutmeg	25	0.96	10%	CS	Feuer (2013)
Cashew	15	4.2	25%		Daouda *et al*. (2017)[24]

[17] Germer, J., Sauerborn, J. (2008) Estimation of the impact of oil palm plantation establishment on greenhouse gas balance. Environ Dev Sustain 10:697–716.

[18] Cheng, C.; Wang, R.; Jiang, J. (2007) Variation of soil fertility and carbon sequestration by planting *Hevea brasiliensis* in Hainan Island, China. J Environ Sci (China) 19:348–352.

[19] Wauters, J.B.; Coudert, S.; Grallien, E.; Jonard, M.; Ponette, Q. (2007) Carbon stock in rubber tree plantations in Western Ghana and Mato Grosso (Brazil). Forest Ecology and Management 255 (2008) 2347–2361

[20] Yang, J-C.; Huang, J.H.; Tang, J-W.; Pan, Q-M.; Han, X-G. (2005) Carbon sequestration in rubber tree plantations established on former arable lands in Xishuangbanna, SW China. Chin J Pan Ecolo, 29(2):296-303

[21] Saengruksawong, C.; Khamyong, S.; Anongrak, N.; Pinthong, J. (2012) Growths and Carbon Stocks of Pará Rubber Plantations on Phonpisai Soil Series in Northeastern Thailand. Rubber Thai Journal, 1, 1–18.

[22] Norgrove L.; Hauser, S. (2013) Carbon stocks in shaded Theobroma cacao farms and adjacent secondary forests of similar age in Cameroon. Trop Ecol. 2013;54(1):15–22.

[23] Biah, I.; Guendehou, S.; Goussanou, C.; Kaire, M.; Sinsin, B. A. (2018) Allometric models for estimating bionass stocks in cashew (Anacardium occidentale L.) plantation in Benin. Bulletin de la Recherche Agronomique du Bénin (BRAB), Numéro 84 –Décembre 2018.

[24] Daouda, B.O.; Saïdou Aliou, Ahoton E. Léonard, Avaligbé J. F. Yasmine, Ezin A. Vincent, Akponikpè P. B. Irénikatché; Aho Nestor (2017) Assessment of organic carbon stock in cashew plantations (Anacardium occidentaleL.) in Benin (West Africa). International Journal of Agriculture and Environmental Research, volume 03, Issue:04. ISSN: 2455-6939.

Clarification Note:

- Most of the values provided in Table 22 are not accompanied by an error range.
- Some publications in Table 22 provide the above-ground biomass accumulated during a certain period of time. The average annual above-ground biomass growth was then calculated on the basis of this information.

Gw - Fallows:

Similar to the estimate of the annual aboveground biomass for Cropland, for fallows the estimate comes from the publication **of** Adu-Bredu *et al*. (2010), who provides the total carbon stock under fallow for three sites (Bawku - **Savannah zone**; Ejura - **Dry Semi-Deciduous Forest zone** and Kakum - **Moist Evergreen zone**) as follows: 39.36 tC ha^{-1} (standard deviation = 3.86); 64.08 tC ha^{-1} (standard deviation = 0.35); and 95.46 tC ha^{-1} (standard deviation = 3.72), respectively. Assuming 5 years fallow and linear growth, the annual average aboveground biomass accumulation is **7.87 tC ha^{-1} yr^{-1}**; **12.82 tC ha^{-1} yr^{-1}**; and **19.09 tC ha^{-1} yr^{-1}**, respectively.

Since these estimates are provided for sites in the three climate zones in Ghana: Dry, Moist and Wet, and since percent distribution to these climate zones was not available for fallows, the estimate of the average annual aboveground biomass growth was calculated as the average of the three estimates provided by Adu-Bredu *et al*. (2010), equal to 13.26 tC ha^{-1} yr^{-1} or 26.52 t d.m. ha^{-1} yr^{-1}. In case the percent distribution for the climate zones, as estimated for the Soil Organic Carbon pool (42% from Dry climate zone; 43% for Moist climate zone; and 15% for Wet climate zone), the weighted average would be 11.68 tC ha^{-1} yr^{-1} [(7.87 x 0.42) + (12.82 x 0.43) + (19.09 x 0.15)] or **23.36 t d.m. ha^{-1} yr^{-1}.**

The IPCC 2019 Refinement provides in Tables 5.1 and 5.2, pages 5.8 – 5.10, updated default coefficients for aboveground biomass and harvest/maturity cycles in agroforestry systems containing perennial species. For fallow in Tropical climate region, the biomass accumulation rate (from Cardinael *et al*., 2018) is 4.42 ± 15% tC ha^{-1} yr^{-1}. Table 5.2 (updated) provides specific values for Africa, for Tropical Dry climate region (5.61 ± 21% tC ha^{-1} yr^{-1}); Tropical Moist for all regions (5.30 ± 75% tC ha^{-1} yr^{-1}); and Tropical Wet (6.21 ± 53% tC ha^{-1} yr^{-1}). Table 24 presents the default values in the 2019 Refinement and the estimates of the average annual aboveground biomass growth using data from from Adu-Bredu *et al.* (2010), assuming a linear biomass growth of 5 years.

Table 23. Some estimates provided for the average annual aboveground biomass growth for fallow (in tC ha^{-1} yr^{-1}).

Climate Region	Average annual aboveground biomass growth (t C ha^{-1} yr $^{-1}$)	Error/Range/CI	Default / Country Specific	Source	AGB (tC ha^{-1})	Harvest /Maturity cycle (yr)
Tropical	4.42	CI: ± 15%	D	2019 IPCC, V4, Ch5. Table 5.1, for Tropical climate region.	22.1 ± 52%	5 ± 50%
Tropical Dry	5.61	CI: ± 22%	D	2019 IPCC, V4, Ch5. Table 5.2, for Africa region	28.05	NA
Tropical Moist	5.30	CI: ± 75%	D	2019 IPCC, V4, Ch5. Table 5.2, for all regions	26.5	NA
Tropical Wet	6.21	CI: ± 53%	D	2019 IPCC, V4, Ch5. Table 5.2, for Africa region	31.05	NA
Bawku - Savannah	7.87	CI: + 19.2%	CS - estimated	Adu-Bredu *et al.* 2010)[25]	39.36 SD: 3.86	Assumed 5 years linear growth based on common management in Ghana
Ejura Dry Semi-Deciduous Forest	12.82	CI: 1.1%	CS - estimated	Adu-Bredu *et al.* 2010)	64.08 SD: 0.35	Assumed 5 years linear growth based on common management in Ghana
Kakum Moist Evergreen Forest	19.09	CI: 7.6%	CS - estimated	Adu-Bredu *et al.* (2010)	95.46 SD: 3.72	Assumed 5 years linear growth based on common management in Ghana

Note:

- The percentage of the CI represents a nominal estimate of error, equivalente to 1.96 times standard deviation, as percentage of the mean[26].

[25] Adu-Bredu, S., Abekoe, M., Tachie-Obeng, E., & Tschakert, P. (2010). Carbon stock under four land use systems in three varied ecological zones in Ghana. In: Carbon sequestration and reduced emissions potentialities in Africa.

[26] This is the way IPCC refers to the % - see, for instance, table 5.1 in the 2006 GLs, footnote 1 - it means that the error is calculated as 2 * (SD/Square root of n) - and this result is divided by the mean to provide the %. 1.96 is used here since it is the correct

8.10 Gw - Grasslands:

For grassland, the average annual aboveground biomass growth was estimated using the estimates provided by the Forest Permanent Plot, reproduced in Table 25, which also includes the default values in the 2019 Refinement. The FPP provides estimates for aboveground biomass for grassland for the following vegetation zones: Dry semideciduous – fire zone, Savannah, Southern Marginal, and Semi-deciduous – NW. These four regions, as estimated by the CE samples, sum up to 96.8% out of the total coverage of the climate zones (refer to Table 23). For tier 1, the 2006 IPCC GLs (Chapter 6, section 6.3.1.1, page 6.25) assumes that grasslands achieve their steady-state biomass during the first year following conversion, so there is only a single year of biomass growth.

A single value for the average annual aboveground biomass growth is provided to Grassland, based on the weighted average of the FPP values and the estimated percentages indicated above. The calculation of the weighted average is as follows: [(1.09 x 0.035) + (12.0 x 0.922) + (1.09 x 0.003) + (1.09 x 0.008)] = 11.11 tC ha^{-1}. Since this value corresponds to 96.8% of the vegetation zones, an expansion to 100% provides a weighted average annual aboveground biomass growth of **11.48 tC ha^{-1} (or 22.96 t d.m. ha^{-1}**).

Table 24. Average annual aboveground biomass growth for grasslands (tC ha^{-1} yr^{-1}).

Climate Region	Average Annual Aboveground Biomass Growth (t C ha^{-1} yr^{-1})	Error/Range/CI	Default / Country Specific	Source
Tropical Dry	6.1	75%	D	2019 IPCC, V4, Ch6. Table 6.4
Tropical Moist	16.1	75%	D	2019 IPCC, V4, Ch6. Table 6.4
Tropical Wet	16.1	75%	D	2019 IPCC, V4, Ch6. Table 6.4
Moist Semideciduous NW	1.09	NA (n=1)	CS	FPP Table 4.8
Dry Semideciduous Fire Zone	1.09	(n=4,SD = 0.30) CI: ± 2.0	CS	FPP Table 4.8
Savannah	12.00	(n=36; SD = 3.27) CI : ± 3.9	CS	FPP Table 4.8
Southern Marginal	1.09	(n=3; SD = 0.30) CI : ± 4.3	CS	FPP, Table 4.8

statistical value for 95% confidence of a normal distribution. The value 1.96 is replaced by the values in the t-distribution when n < 30. When n is not provided, the calculation is 1,96 * SD/mean. the CI would be (plus / minus) 1,96 SD/squared root of n - for n<30, divided by square root of n-1. This would give the CI which, divided by the sample mean, provides the %.

Note:

- The confidence interval (CI) was estimated as ± $t_{a/2}$ x SD/sqrt(n-1), where $t_{a/2}$ is the value in the t-Student distribution with n-1 degrees of freedom, for 95% confidence (or a/2 = 0.025), sqrt is the square root, n is the sample size and SD is the standard deviation.

8.11 Root-to Shoot Ratios (R)

Equation 2.10 in the 2006 IPCC GLs, provided above, requires the ratio of below-ground biomass to above-ground biomass estimation (root-to-shoot ratio - R), which are addressed in sequence for Forest Land, Cropland and Grassland. Table 26 provides the summary results which are detailed in sequence.

Table 25. Weighted ratios of below-ground biomass to above-ground biomass for specific vegetation type, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$.

R: BLG : ABG Ratio				
LU	Sub-Category	Value	Range / Error	Source
F	Wet Evergreen	0.07	NE, as the two variables are not independent and the covariance is not provided for the calculation of the ratio of the two standard deviations	Weighted average open and closed
	Moist Evergreen	0.17	NE	Weighted average open and closed
	Moist Semideciduous SE	0.18	NE	Weighted average open and closed
	Moist Semideciduous NW	0.38	NE	Weighted average open and closed
	Upland Evergreen	0.33	NE	Weighted average open and closed
	Dry Semideciduous (Inner Zone)	0.64	NE	Weighted average open and closed
	Dry Semideciduous (Fire Zone)	0.29	NE	Weighted average open and closed
	Savannah	0.29	NE	Weighted average open and closed
	Southern Marginal	1.31	NE	Weighted average open and closed
C	Annual crops	0	NE	Assumption that the R is zero
	Perennial crops	0	NE	Assumption that the R is zero
	Fallow Lands	0	NE	Assumption that the R is zero
G	Grassland Dry	0.35	NE	Weighted average dry and moist/wet

W	Wetlands	0	NE	Assumption that the R is zero
S	Settlements	0	NE	Assumption that the R is zero
O	Other lands	0	NE	Assumption that the R is zero

Clarification Note:

- The standard deviations of the root-to-shoot ratios have not been estimated as explained above. The standard deviations of the below-ground biomass estimates in Table 4.8 of the Report on Mapping of Forest Cover and Carbon Stock in Ghana are very high (e.g., for closed forest in Wet Evergreen, the standard deviation of the below-ground biomass is 72.03 t d.m. ha^{-1}; for closed forest in Upland Evergreen it is 134 t d.m. ha^{-1}). So it is to be expected that the confidence interval for R is large. A proxy calculation with the weighted standard deviation multiplied by 1,96 would result in a value of 295.67.

8.11.1 R- Forest Land

The estimates of root-to-shoot ratios in Table 26 for the vegetation zones in Forest Land correspond to the weighted average of root-to-shoot ratios in open and closed forests and are estimated using data in Table 27 *(Percent Distribution of Open and Closed Forests in each Vegetation Zone)*, Table 28*(Root-to-shoot ratios for each vegetation zones in open and closed forests and the weighted root-to-shoot ratios)* and Table 29 *(Above and below-ground biomass estimates for each vegetation zones in open and closed forests).*

The above and below-ground biomass are country-specific, and resulted from the Forest Preservation Programme (FPP). The data, provided in tC ha^{-1} in Table 4.8 in the Report on Mapping of Forest Cover and Carbon Stocks in Ghana have been converted to t d.m. ha^{-1} using the carbon fractions of dry matter presented in Table 12.

Table 26. Percentage Distribution of Open and Closed Forest in each Vegetation Zone - Forest Land.

Veg zone - Open Forest	Area	% Total	% Veg Zone
Dry semideciduous (fire zone)	13188	0.29%	3.08%
Dry semideciduous (inner zone)	19781	0.43%	8.11%
Moist evergreen	5728	0.12%	1.09%
Moist semideciduous (north west subtype)	14738	0.32%	4.11%
Moist semideciduous (south east subtype)	16937	0.37%	5.00%
Savannah	290126	6.30%	12.09%
Southern marginal	13188	0.29%	28.57%
Upland evergreen	956	0.02%	3.59%
Wet evergreen	6667	0.14%	2.78%
Total Open	381307	8.28%	

Veg zone - Closed Forest	Area	% Total	% Veg Zone
Dry semideciduous (fire zone)	415408	9.02%	96.92%
Dry semideciduous (inner zone)	224188	4.87%	91.89%
Moist evergreen	518098	11.25%	98.91%
Moist semideciduous (north west subtype)	344171	7.47%	95.89%
Moist semideciduous (south east subtype)	321876	6.99%	95.00%
Savannah	2110007	45.80%	87.91%
Southern marginal	32969	0.72%	71.43%
Upland evergreen	25646	0.56%	96.41%
Wet evergreen	232832	5.05%	97.22%
Total closed	4225194	91.72%	

Source: Collect Earth assessment by GFC.

Table 27. Root-to-shoot (R) estimates for each vegetation zone in open and closed Forest Land and the weighted root-to-shoot ratio [in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$].

Vegetation Zone	Forest Type	Value	Error/Range	Source	Notes
Wet Evergreen (WETVER)	Open	0.200		FPP, TABLE 4.8	n = 0 % OPEN = 2.78
	Closed	0.064		FPP, TABLE 4.8	n = 5 % CLOSED = 97.22
	Weighted Average	0.068			
Moist Evergreen (MEVER)	Open	0.075		FPP, TABLE 4.8	n = 6 % OPEN = 1.09
	Closed	0.174		FPP, TABLE 4.8	n = 30 % CLOSED = 98.91
	Weighted Average	0.173			
Moist Semi-deciduous SE (MSEMSE)	Open	0.217		FPP, TABLE 4.8	n = 7 % OPEN = 5.0
	Closed	0.188		FPP, TABLE 4.8	n = 9 % CLOSED = 95.0
	Weighted Average	0.189			
Moist Semi-deciduous NW (MSEMNW)	Open	0.515		FPP, TABLE 4.8	n = 0 % OPEN = 4.11
	Closed	0.378		FPP, TABLE 4.8	n = 45 % CLOSED = 95.89
	Weighted Average	0.384			
Upland Evergreen (UPEVER)	Open	0.490		FPP, TABLE 4.8	n = 6 % OPEN = 3.59
	Closed	0.321		FPP, TABLE 4.8	n = 15 % CLOSED = 96.41
	Weighted Average	0.327			

Dry Semideciduous (Fire Zone) Forest	Open	0.659		FPP, TABLE 4.8	n = 11 % OPEN = 3.08
	Closed	0.280		FPP, TABLE 4.8	NE = 0 % CLOSED = 96.92 Since the was no belowground estimate for closed forest, the default value in the 2006 IPCC GLs in Table 4.4 for Tropical Dry Forest was used.
	Weighted Average	0.292			
Dry Semideciduous (Inner Zone) Forest	Open	0.712		FPP, TABLE 4.8	n = 9 % OPEN = 8.11
	Closed	0.635		FPP, TABLE 4.8	n = 1 % CLOSED = 91.89
	Weighted Average	0.642			
Savannah Forest	Open	0.354		FPP, TABLE 4.8	n = 12 % OPEN = 12.09
	Closed	0.280		FPP, TABLE 4.8	n = 0 % CLOSED = 87.91. Since the was no belowground estimate for closed forest, the default value in the 2006 IPCC GLs in Table 4.4 for Tropical Dry Forest was used.
	Weighted Average	0.289			
Southern Marginal Forest	Open	0.807		FPP, TABLE 4.8	n = 4 % OPEN = 28.57

	Closed	1.512		FPP, TABLE 4.8	n = 3 % CLOSED = 71.43
	Weighted Average	1.311			

Table 28. Above and below-ground biomass for open and closed forests in each vegetation zone used in the estimation of the root-to-shoot ratios in table 21 (t d.m. ha^{-1}).

Vegetation Zone	Forest Type	AGB t d.m. ha^{-1}	BGB t d.m. ha^{-1}	Source	Notes
Wet Evergreen (WETVER)	Open	64.40	12.87	FPP, TABLE 4.8	n = 0
	Closed	264.02	16.83	FPP, TABLE 4.8	n = 5
Moist Evergreen (MEVER)	Open	84.72	6.38	FPP, TABLE 4.8	n = 6
	Closed	296.51	51.64	FPP, TABLE 4.8	n = 30
Moist Semi-deciduous SE (MSEMSE)	Open	74.85	16.25	FPP, TABLE 4.8	n = 7
	Closed	262.87	49.32	FPP, TABLE 4.8	n = 9
Moist Semi-deciduous NW (MSEMNW)	Open	37.15	19.15	FPP, TABLE 4.8	n = 0
	Closed	85.87	32.50	FPP, TABLE 4.8	n = 45
Upland Evergreen (UPEVER)	Open	55.70	27.27	FPP, TABLE 4.8	n = 6
	Closed	155.51	49.90	FPP, TABLE 4.8	n = 15
Dry Semideciduous	Open	25.53	16.83	FPP, TABLE 4.8	n = 11

(Fire Zone) Forest	Closed	32.49	NE	FPP, TABLE 4.8	NE = 0
Dry Semideciduous (Inner Zone) Forest	Open	30.17	21.47	FPP, TABLE 4.8	n = 9
	Closed	49.32	31.33	FPP, TABLE 4.8	n = 1
Savannah Forest	Open	27.85	9.86	FPP, TABLE 4.8	n = 12
	Closed	37.72	NE	FPP, TABLE 4.8	n = 0
Southern Marginal Forest	Open	17.98	14.51	FPP, TABLE 4.8	n = 4
	Closed	23.79	35.98	FPP, TABLE 4.8	n = 3

Clarification Note:

- The below-ground biomass was estimated using allometric equations developed during the Forest Preservation Programme (see Table 36 (b)).

8.11.2 R- Cropland

Root-to-shoot ratios for Cropland have not been estimated in this submission since the data for Cropland generated from the Forest Preservation Program did not differentiate between annual and perennial Cropland. In addition, the default assumption in the 2006 IPCC GLs, volume 4, chapter 5, pg. 5.10 is that there is no change in below-ground biomass of perennial trees in agricultural systems and that default values for below-ground biomass for these systems are not available.

8.11.3 R - Grassland

The Forest Preservation Program provided estimates for above and below-ground biomass in grassland for some vegetation zones, which were used here to generate the root-to-shoot ratios for grassland, as indicated in Table 30. The table also includes the percent cover distribution for each vegetation zone where FPP samples were collected for grassland (refer to Table 30).

Table 29. Estimation of the root-to-shoot ratios for Grassland.

Vegetation Zone	AGB tC ha^{-1}	BGB tC ha^{-1}	R	Percentage Cover (%)
Moist Semideciduous (north-west subtype)	1.09	2.18	2.00	0.008
Dry Semideciduous (fire zone)	1.09	0.27	0.25	0.035
Savannah	12.0	3.82	0.32	0.922
Southern Marginal	1.09	5.73	5.26	0.003
Percentage Total				0.968

The weighted average root-to-shoot ratio for grassland was calculated from data in Table 30 and in Table 31 as follows: [(2.00 x 0.008) + (0.25 x 0.035) + (3.82 x 0.922) + (5.73 x 0.003)] = 0.334). Since the sample plots for grassland cover 96.8% of the total area, an expansion to 100% provides **R = 0.35.** This value is well below that suggested in the 2006 IPCC GLs, volume 4, Ch. 6, Table 6.1 for Tropical Dry climate zone, equal to 2.8.

Table 30. Percentage Distribution by Vegetation Zones for Grasslands

Climate Zone	Vegetation Zone	Area [Ha] (final LU)	Percentages (%)
DRY	Dry semideciduous (fire zone)	145063	3.5%
DRY	Dry semideciduous (inner zone)	52750	1.3%
DRY	Savannah	3830981	92.2%
DRY	Southern marginal	13188	0.3%
MOIST	Moist evergreen	20990	0.5%
MOIST	Moist semideciduous (north west subtype)	33549	0.8%
MOIST	Moist semideciduous (south east subtype)	49930	1.2%
MOIST	Upland evergreen	1434	0.0%
WET	Wet evergreen	8895	0.2%

As previously indicated, the FREL/FRL estimation is based on the IPCC Gain – Loss method. The information above was relevant for the annual "gains" in above and below-ground biomass for Forest Land, Cropland and Grassland. The "losses" or annual decreases in carbon stocks are now addressed.

Annual decrease in carbon stocks due to biomass losses in land remaining in the same land-use category (Equation 2.11, Ch2, V4)

$$\Delta C_L = L_{wood-removals} + L_{fuelwood} + L_{disturbance}$$

Where:

ΔC_L = annual decrease in carbon stocks due to biomass loss in land remaining in the same land-use category, tonnes C yr^{-1}

$L_{wood-removals}$ = annual carbon loss due to wood removals, tonnes C yr^{-1} (Equation 2.12 in the 2006 IPCC GLs, reproduced below)

$L_{fuelwood}$ = annual biomass carbon loss due to fuelwood removals, tonnes C yr^{-1} (See Equation 2.13 in the 2006 IPCC GLs, reproduced below)

$L_{disturbance}$ = annual biomass carbon losses due to disturbances, tonnes C yr^{-1} (See Equation 2.14 in the 2006 IPCC GLs, reproduced below)

Annual carbon loss in biomass of wood removals (Equation 2.12, Ch2, V4)

$$L_{wood-removals} = \{H \bullet BCEF_R \bullet (1+R) \bullet CF\}$$

Where:

$L_{wood-removals}$ = annual carbon loss due to biomass removals, tonnes C yr^{-1}

H = annual wood removals, roundwood, m^3 yr^{-1}

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$. R must be set to zero if assuming no changes of below-ground biomass allocation patterns (Tier 1).

CF = carbon fraction of dry matter, tonne C (tonnes d.m.)$^{-1}$

$BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark), tonnes biomass removal (m^3 of removals)$^{-1}$

Table 31. Annual carbon loss in biomass of wood removals (tonnes C yr^{-1}).

H = annual wood removals, roundwood, tonnes C yr^{-1}			
LU	Sub-Category	Sources	Notes
F	Wet Evergreen	NA	IE
	Moist Evergreen	NA	IE
	Moist Semideciduous SE	NA	IE
	Moist Semideciduous NW	NA	IE
	Upland Evergreen	NA	IE
	Dry Semideciduous (Inner Zone)	NA	IE
	Dry Semideciduous (Fire Zone)	NA	IE
	Savannah	NA	IE
	Southern Marginal	NA	IE

Clarification Notes:

Wood removals were estimated as canopy cover loss during the Collect Earth assessment; losses are reported as disturbances due to logging using eq. 2.14 in the 2006 IPCC GLs, as provided in sequence.

Annual carbon loss in biomass of fuelwood removal (Equation 2.13, Ch2, V4)

$$L_{fuelwood} = [\{FG_{trees} \bullet BCEF_R \bullet (1+R)\} + FG_{part} \bullet D] \bullet CF$$

Where:

$L_{fuelwood}$ = annual carbon loss due to fuelwood removals, tonnes C yr^{-1}

FG_{trees} = annual volume of fuelwood removal of whole trees, m^3 yr^{-1}

FG_{part} = annual volume of fuelwood removal as tree parts, m^3 yr^{-1}

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$

CF = carbon fraction of dry matter, tonne C (tonnes d.m.)$^{-1}$

D = basic wood density, tonnes d.m. m^{-3}

$BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to biomass removals (including bark), tonnes biomass removal (m^3 of removals)$^{-1}$

Table 32. Annual carbon loss in biomass of fuelwood removal

FG_{trees} = annual volume of fuelwood removal of whole trees (tC yr^{-1}) / FG_{part} = annual volume of fuelwood removal as tree parts (tC yr^{-1})			
LU	Sub-Category	Source	Notes
FL	Wet Evergreen	NA	IE
	Moist Evergreen	NA	IE
	Moist Semideciduous SE	NA	IE
	Moist Semideciduous NW	NA	IE
	Upland Evergreen	NA	IE
	Dry Semideciduous (Inner Zone)	NA	IE
	Dry Semideciduous (Fire Zone)	NA	IE
	Savannah	NA	IE
	Southern Marginal	NA	IE

Clarification Notes:

Fuelwood removals were estimated as canopy cover loss during the Collect Earth assessment; losses are reported as disturbances due to logging using eq. 2.14 in the 2006 IPCC GLs, as provided in sequence.

Annual carbon losses in biomass due to disturbances (Equation 2.14, Ch2, V4)

$$L_{disturbance} = A_{disturbance} \bullet B_W \bullet (1+R) \bullet CF \bullet fd$$

Where:

$L_{disturbance}$ = annual other losses of carbon, tonnes C yr^{-1}

$A_{disturbance}$ = area affected by disturbances, ha yr^{-1}

B_W = average above-ground biomass of land areas affected by disturbances, tonnes d.m. yr^{-1}

R = ratio of below-ground biomass to above-ground biomass, in tonnes d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$

CF = carbon fraction of dry matter, tonne C (tonnes d.m.) $^{-1}$

fd = fraction of biomass lost in disturbance

Table 34 provides the weighted average aboveground biomass of open and closed forests affected by disturbances (BW). To estimate the weighted average the percentages of open and closed forests from each vegetation zone in Table 27 are used, jointly with data from Table 30, which provides the above-ground biomass for open and closed forests for each ecological zone.

As an example of calculation, the value 258.4 t d.m. ha^{-1} for Wet Evergreen vegetation zone results from the following calculation:

From Table 27: % open = 2.78% ; % closed = 97.22%

From Table 36: above-ground biomass for open forest in Wet Evergreen = 64.40 t d.m. ha^{-1} and for closed forest = 264.02 t d.m. ha^{-1}.

The weighted average aboveground biomass for the Wet Evergreen vegetation zone is then: (0.0278 x 64.40 + 0.9722 x 264.02) = 258.47 t d.m. ha^{-1}.

The summary calculations are provided in Table 34 for all vegetation zones.

Table 33. Weighted average above-ground biomass of land areas affected by disturbances, tonnes d.m. ha^{-1}.

B_W = average above-ground biomass of land areas affected by disturbances, tonnes d.m. ha^{-1}				
LU	Sub-Category	Value	Range / Error	Notes
F	Wet Evergreen	258.47	± 1.66	Average open closed
	Moist Evergreen	294.20	± 0.38	Average open closed
	Moist Semideciduous SE	253.5	± 1.83	Average open closed
	Moist Semideciduous NW	83.8	± 0.21	Average open closed
	Upland Evergreen	151.9	± 1.00	Average open closed
	Dry Semideciduous (Fire Zone)	32.28	± 1.13	Average open closed
	Dry Semideciduous (Inner)	47.82	± 0,06	Average open closed

	Savannah	36.53	± 0.05	Average open closed
	Southern Marginal	22.13	± 14.79	Average open closed
C	Annual crops	10		For only one year after conversion
	Perennial crops	106.80		Weighted average aboveground biomass: Rubber, Cocoa, Oil Palm, Other permanent.
	Fallow Lands	132.60		Adu-Bredu *et al.* (2010)
G	Grasslands	22.96		Weigthed Average by Vegetation Zone, For only one year after conversion
W	Wetlands	0		NA
S	Settlements	0		NA
O	Other lands	0		NA

Clarification Notes:

Bw- Forest lands:

The aboveground biomass estimates in Table 36 for open and closed forests in each vegetation zone are country-specific estimates obtained from the Forest Preservation Programme. The programme developed several allometric equations for Dry, Moist and Wet zones in Ghana. The equations presented in Table 35 were selected as those appropriate to estimate the aboveground biomass for each vegetation zone. The selection took into account the relationship of biophysical parameters (height, diameter) with aboveground biomass, as represented by the root square (R^2) and the root mean square error (RMSE) provided in Table 35 (a). The aboveground biomass for all open and closed forests in all vegetation zones are provided in Table 36. Table 35(b) also includes the allometric equations for estimating below-ground biomass, also developed by the Forest Preservation Programme.The below-ground estimates were included in Table 29 and used to estimate the root-to-shoot ratios in open and closed forests for each ecological zone.

Table 34. Allometric equations used to estimate (a) aboveground biomass and (b) below-ground biomass (b) in trees for the broad Dry, Moist and Wet zones and the corresponding R-squared and root mean squared error (RMSE) values.

(a) Above-ground biomass:

		a	b	R^2	RMSE
Dry Zone • Savannah, • Dry Semideciduous • Southern Margin	Trees with measured height and height below 25 meters: $Y=a*(Ht*D^2)^b$	0.0139	1.0379	0.81803	615.8164
	Trees without measured height or with height above 25 meters : $Y=a(D^2)^b$	0.6494	0.9817	0.7517	719.339
Moist Zone • Moist-Semideciduous SE • Moist-Semideciduous NW • Upland Evergreen	Trees with measured height: $Y=a*(Ht*D^2)^b$	0.00153	1.2078	0.9724	933.37
	Trees without measured height: $Y=a(D^2)^b$	0.00388	1.6063	0.9498	1258.82
Wet Zone • Evergreen • Moist Evergreen	Trees with measured height and with height below 25 meters: $Y=a*(Ht*D^2)^b$	0.00153	1.2078	0.9724	933.37
	Trees without measured height or with height above 25 meters: $Y=a(D^2)^b$	0.2471	1.1783	0.9595	1128

(b) Below-ground biomass

		a	b	R^2	RMSE
Dry Zone • Savannah, • Dry Semideciduous • Southern Margin	Trees with measured height $Y=a*(Ht*D^2)^b$	1.3928	0.3664	0.358587	7.946294
	Trees without measured height: $Y=a(D^2)^b$	1.0442	0.5797	0.31492	8.212331
Moist Zone • Moist-Semideciduous SE • Moist-Semideciduous NW • Upland Evergreen	Trees with measured height: $Y=a*(Ht*D^2)^b$	0.5746	0.5091	0.489865	36.47425
	Trees without measured height: $Y=a(D^2)^b$	2.3174	0.5322	0.427698	38.63283
Wet Zone • Evergreen	Trees with measured height: $Y=a*(Ht*D^2)^b$	0.0057	0.9598	0.94663	39.215087

Table 35. Estimates of aboveground biomass (AGB) by vegetation zone and forest type (t d.m. ha^{-1}) and weighted average for each vegetation zone.

Vegetation Zone	Forest Type	AGB (t d.m. ha)	CI (95%)	Source
Wet Evergreen (WETVER)	Open	64.4	NA (n=0)	FPP, Table 4.8 % OPEN = 2.78
	Closed	264.02	(n=5); CI: + 0.69%	FPP, Table 4.8 % CLOSED = 97.22
	Weighted Average	258.47		
Moist Evergreen (MEVER)	Open	84.72	(n=6); CI: + 1.22%	FPP, Table 4.8 % OPEN = 1.09
	Closed	296.51	(n=30); CI:0.11%.	FPP, Table 4.8 % CLOSED = 98.91
	Weighted Average	294.20		
Moist Semi-deciduous SE (MSEMSE)	Open	74.85	(n=7); CI: + 3.56%	FPP, Table 4.8 % OPEN = 5.00
	Closed	262.87	(n=9) CI: + 0.67%	FPP, Table 4.8 % CLOSED = 95.00

	Weighted Average	253.47		
Moist Semi-deciduous NW (MSEMNW)	Open	37.13	(n=24) CI: + 0.90%	FPP, Table 4.8 % OPEN = 4.11
	Closed	85.87	(n=45) CI: + 0.24%	FPP, Table 4.8 % CLOSED = 95.89
	Weighted Average	83.87		
Upland Evergreen (UPEVER)	Open	55.70	(n=6) CI: + 3.82%	FPP, Table 4.8 % OPEN = 3.59
	Closed	155.51	(n=15) CI: + 0.58%	FPP, Table 4.8 % CLOSED = 96.41
	Weighted Average	151.93		
Dry Semideciduous (Fire Zone) Forest	Open	25.53	(n=11) CI: + 3.01%	FPP, Table 4.8 % OPEN = 3.08
	Closed	32.49	(n=1)	FPP, Table 4.8 % CLOSED = 96.96
	Weighted Average	32.28		
Dry Semideciduous (Inner Zone) Forest	Open	30.17	(n=9) CI: + 5.10%	FPP, Table 4.8 % OPEN = 8.11
	Closed	49.32	(n=1)	FPP, Table 4.8 % CLOSED = 91.89
	Weighted Average	47.82		
Savannah Forest	Open	27.85	(n=12) CI: + 2.03%	FPP, Table 4.8 % OPEN = 12.09
	Closed	37.72	(n=0)	FPP, Table 4.8 % CLOSED = 87.91
	Weighted Average	36.53		
Southern Marginal Forest	Open	17.98	(n=4) CI: + 35.69%	FPP, Table 4.8 % OPEN = 28.57
	Closed	23.79	(n=3) CI: + 65.37%	FPP, Table 4.8 % CLOSED = 71.43
	Weighted Average	22.13		

Note:

- Values in the Report on Mapping of Forest Cover and Carbon Stock from the Forest Preservation Programme are presented in tC ha^{-1}. Therefore, values were converted to t.d.m ha^{-1} by AGB tC*/CF=0.47. The same applies for the estimates of standard deviation.

Bw - Croplands:

AGB – Annual crops:

The aboveground biomass of annual crops was taken as the default value of 5 tC ha^{-1} (or **10 t dm ha^{-1}**) in the 2006 IPCC GLs.

AGB – Perennial Crops:

For perennial crops, the weighted average above-ground biomass follows the rationale presented to estimate the average annual above-ground biomass growth, assuming that perennial crops reach the biomass steady-state in 20 years. Hence the estimate for the above-ground biomass for perennial crops is 53.40 tC ha^{-1} (or **106.80 t d.m. ha^{-1}**). Table 37 provides estimates for above-ground biomass for the main crops in Ghana (cocoa, oil palm, rubber, citrus, cashews etc.

Table 36. Above-ground biomass for major perennial crops).

Type	Age (years)	Above ground (tC ha^{-1})	Error	Default/ Country Specific/ Other Region	Source
Cocoa	21	65.0		CS	Kongsager *et al.* (2013)
Cocoa	8	20.0		CS	Isaac *et al.* (2007)
Cocoa	30	76,2		CS	Feuer (2013)
Cocoa	8	8.6		CS	Owusu *et al.* (2018)
Cocoa	8	10.3		CS	Isaac *et al.* (2007)
Cocoa	15	16.8		CS	Isaac *et al.* (2005)
Cocoa	20	23.0		CS	Asigbaase et al. (2020)
Cocoa	3	12.7		CS	Dawoe (2009)
Oil palm	7	21.7		CS	Kongsager *et al.* (2013)
Oil palm	16	28.0		CS	Kongsager *et al.* (2013)
Oil palm	23	45.3		CS	Kongsager *et al.* (2013)
Oil palm	25	25 - 50			Germer and Sauerborn (2008)
Oil palm	25	25 - 50		CS	Feuer (2013)
Rubber	12	61.5		CS	Kongsager *et al.* (2013)
Rubber	44	213.6		CS	Kongsager *et al.* (2013)
Rubber	30	272,1			Cheng *et al*. (2007)
Rubber	14	76.4		CS	Wauters *et al*. (2007)
Rubber	23	186,2			Yang *et al.* (2005)
Rubber	15	70.1			Saengruksawong *et al.*(2012)
Rubber	30	14.4			Norgrove and Hauser (2013)
Rubber	20	92.6		CS	Feuer (2013)
Orange	25	76.3		CS	Kongsager et al. (2013)
Citrus	20	61.4		CS	Feuer (2013)
Cashew	4	11.2		CS	Biah *et al.* (2018)
Cashew	15	63.0			Daouda *et al.* (2017)
Yang Lang	10	18.9		CS	Feuer (2013)
Black Peper	8	60.2		CS	Feuer (2013)

Nutmeg	15	63.0		CS	Feuer (2013)

AGB - Fallows:

Above-ground biomass for fallows were estimated using the results in Adu-Bredu *et al*. (2010). Table 38 provides these estimates and also includes, for reference sake, the updated default values for aboveground biomass and harvest/maturity cycles in agroforestry systems containing perennial species (fallows), in the 2019 Refinement (Tables 5.1 and 5.2, pages 5.8 – 5.10). The average above-ground biomass in fallow was estimated as the mean of the values in Adu-Bredu *et a.l* (2010), equal to 66.3 tC ha^{-1} (or **132.60 t d.m. ha^{-1}**).

In case the percent distribution for the climate zones, as estimated for the Soil Organic Carbon pool (42% from Dry climate zone; 43% for Moist climate zone; and 15% for Wet climate zone), the weighted average would be 58.40 tC ha^{-1} [(39.36 x 0.42) + (64.08 x 0.43) + (95.46 x 0.15)) or 116.81 t d.m. ha^{-1}.

Table 37. Above-ground biomass estimates for fallows from Adu-Bredu et al. (2010).

Climate Region	AGB (t C ha^{-1})	Error/Range/CI	Default / Country Specific	Source	Harvest /Maturity cycle (yr)
Tropical	22.1	CI: ± 52%	D	2019 IPCC, V4, Ch5. Table 5.1	5 ± 50%
Tropical Dry	28.05	CI: ± 52%	D	2019 IPCC, V4, Ch5. Table 5.2	5 ± 50%
Tropical Moist	26.5	CI: ± 52%	D	2019 IPCC, V4, Ch5. Table 5.2	5 ± 50%
Tropical Wet	31.05	CI: ± 52%	D	2019 IPCC, V4, Ch5. Table 5.2	5 ± 50%
Savannah	39.36	SD: 3.86 CI: 19.22%	CS	Adu-Bredu *et al.* 2010[27]	5 ± 50%
Dry Semi-Deciduous Forest	64.08	SD: 0.35 CI: 1.08%	CS	Adu-Bredu *et al.* 2010[28]	5 ± 50%
Moist Evergreen Forest	95.46	SD: 3.72 CI: 7.64%	CS	Adu-Bredu *et al.* 2010[29]	5 ± 50%

Clarification Note:

- For the estimates from Adu-Bredu *et al.* (2010), the error represents a nominal estimate of error, equivalent to 1.96 times the standard deviation, as a percentage of the mean.

AGB - Grassland:

For Grassland, the above-ground biomass is equal to the estimate provided in Table 25 (Average annual above-ground biomass growth for Grasslands), since for Tier 1, the 2006 IPCC GLs (Chapter 6, section 6.3.1.1, page 6.25) assumes that grasslands achieve their steady-state biomass during the first year following conversion, so there is only a single year of biomass growth. The estimates for the average above-

[27] Adu-Bredu, S., Abekoe, M., Tachie-Obeng, E., & Tschakert, P. (2010). Carbon stock under four land use systems in three varied ecological zones in Ghana.

[28] Adu-Bredu, S., Abekoe, M., Tachie-Obeng, E., & Tschakert, P. (2010). Carbon stock under four land use systems in three varied ecological zones in Ghana.

[29] Adu-Bredu, S., Abekoe, M., Tachie-Obeng, E., & Tschakert, P. (2010). Carbon stock under four land use systems in three varied ecological zones in Ghana.

ground biomass in Table 39 reproduce those in Table 25. The default values in the 2019 Refinement are included in the table for reference only.

Table 38. Average above-ground biomass for grassland (tC ha^{-1}).

Climate Region	Average Annual Aboveground Biomass (t C ha-^{1})	Error/Range/CI	Default / Country Specific	Source
Tropical Dry	6.1	75%	D	2019 IPCC, V4, Ch6. Table 6.4
Tropical Moist	16.1	75%	D	2019 IPCC, V4, Ch6. Table 6.4
Tropical Wet	16.1	75%	D	2019 IPCC, V4, Ch6. Table 6.4
Moist Semideciduous NW	1.09	NA (n=1)	CS	FPP Table 4.8
Dry Semideciduous Fire Zone	1.09	(n=4,SD=1.09) CI: 64%	CS	FPP Table 4.8
Savannah	12.00	(n=36; SD = 12) CI : 57%	CS	FPP Table 4.8
Southern Marginal	1.09	(n=3; SD = 1,09) CI : 97%	CS	FPP, Table 4.8

Clarification Note:
For tier 1 methods, the 2006 IPCC GLs (Chapter 6, section 6.3.1.1, page 6.25) assumes that Grasslands achieve their steady-state biomass during the first year following conversion.

Equation 2.14 in the 2006 IPCC GLs requires the fraction of biomass lost in disturbance, which is provided in Table 40 for each vegetation zone and the disturbance events fire, logging and other disturbances.

Fraction of biomass lost in disturbance (fd)

Table 39. Fraction of biomass lost in disturbance from fire, logging and other disturbance events.

Vegetation Zone	Disturbance	Fraction of Disturbance	Notes
Wet Evergreen (WETVER)	Affected by Fire	2%	As a result of slash and burn agriculture
	Affected by Logging	25%	Timber harvesting
	Affected by Other disturbances	40%	Surface mining (legal and illegal), farming
Moist Evergreen (MEVER)	Affected by Fire	5%	As a result of slash and burn agriculture
	Affected by Logging	35%	Timber harvesting and illegal chainsaw activities
	Affected by Other disturbances	40%	Farming in forest reserves and moderate surface mining
Moist Semi-deciduous SE (MSEMSE)	Affected by Fire	15%	Part made up of grassland
	Affected by Logging	30%	Timber harvesting
	Affected by Other disturbances	35%	Surface mining (legal and illegal), farming
Moist Semi-deciduous NW (MSEMNW)	Affected by Fire	20%	Part made up of grassland
	Affected by Logging	30%	Timber harvesting
	Affected by Other disturbances	40%	Surface mining (legal and illegal), farming
Upland Evergreen (UPEVER)	Affected by Fire	1%	
	Affected by Logging	5%	Chainsawing and minimal timber harvesting
	Affected by Other disturbances	10%	Surface mining (legal and illegal), farming
Dry Semideciduous (Fire Zone) Forest	Affected by Fire	40%	rampant bushfires
	Affected by Logging	10%	Chainsaw and timber harvesting
	Affected by Other disturbances	35%	Farming, grazing and fuelwood harvesting
Dry Semideciduous (Inner Zone) Forest	Affected by Fire	40%	Rampant bushfires
	Affected by Logging	5%	Chainsawing and Illegal rosewood harvesting
	Affected by Other disturbances	10%	Fuelwood harvesting, grazing and farming
Savannah Forest	Affected by Fire	65%	Large area covered by grass
	Affected by Logging	5%	Rosewood harvesting
	Affected by Other disturbances	30%	Farming, grazing and fuelwood harvesting
Southern Marginal Forest	Affected by Fire	25%	Part covered with grass and shrub
	Affected by Logging	2%	Chainsaw activities
	Affected by Other disturbances	5%	Farming, fuelwood, harvesting and grazing

Clarification Notes:

During the Collect Earth assessment, the interpreters could identify the canopy cover loss due to disturbance. This fraction is less than the percentages assigned as hierarchies for classification. For example, a plot mixed of forest and settlements, with 20% or more settlements, was classified as settlement; however, if the percentage was less than 20%, the plot was classified as Forest land disturbed. These disturbances were Fire, logging understood as a piece of land cleared or canopy cover lost, and other disturbances such as grazing, infrastructure and other human impacts. These fractions are the average of what was identified as fraction lost during a disturbance in all plots classified as such. The information observed in CE was crosschecked with National Experts *(see Expert Judgement Table # 1, attached Excel file).*

The areas affected by disturbances, $A_{disturbance}$, required in equation 2.14 in the 2006 IPCC GLs are provided below from 2000-2001 until 2014-2015.

$A_{disturbance}$ - area affected by disturbances, ha yr^{-1}

DISTURBANCES

	Land Use and Land Use Change (LULUC) Vertical: Inicial Use Horizontal: Disturbance	*Affected by Fire*	*Affected by Logging*	*Affected by other disturbances*	**TOTAL**
2014-2015	*Wet Evergreen Forest*			1213	1,213
	Moist Evergreen Forest		2547	1273	3,820
	Moist Semi-deciduous SE Forest		640	1211	1,851
	Moist Semi-deciduous NW Forest		7415	618	8,033
	Upland Evergreen Forest		159		159
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest				0
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	0	10,761	4,315	**15,076**

DISTURBANCES

Land Use and Land Use Change (LULUC)

Vertical: Inicial Use
Horizontal: Disturbance

2013-2014

Land Use and Land Use Change (LULUC)	Affected by Fire	Affected by Logging	Affected by other disturbances	TOTAL
Wet Evergreen Forest		606		606
Moist Evergreen Forest		637	1273	1,910
Moist Semi-deciduous SE Forest		1920		1,920
Moist Semi-deciduous NW Forest		2472	618	3,090
Upland Evergreen Forest			159	159
Dry Semidecidouos (Fire Zone) Forest				0
Dry Semidecidouos (Inner Zone) Forest				0
Savannah Forest	13188			13,188
Southern Marginal Forest				0
Croplands, Annual Crops				0
Croplands, Perennial Crops				0
Croplands, Fallow				0
Grasslands (Pasture / Savannahs / Shrublands)				0
Wetland				0
Settlement				0
Other Lands				0
TOTAL	13,188	5,635	2,051	20,873

2012-2013

Land Use and Land Use Change (LULUC)	Affected by Fire	Affected by Logging	Affected by other disturbances	TOTAL
Wet Evergreen Forest			606	606
Moist Evergreen Forest		637	637	1,273
Moist Semi-deciduous SE Forest	1280	640	3131	5,052
Moist Semi-deciduous NW Forest		2449	2426	4,874
Upland Evergreen Forest				0
Dry Semidecidouos (Fire Zone) Forest				0
Dry Semidecidouos (Inner Zone) Forest			6594	6,594
Savannah Forest				0
Southern Marginal Forest				0
Croplands, Annual Crops				0
Croplands, Perennial Crops				0
Croplands, Fallow				0
Grasslands (Pasture / Savannahs / Shrublands)				0
Wetland				0
Settlement				0
Other Lands				0
TOTAL	1,280	3,726	13,394	18,400

2011-2012

Land Use and Land Use Change (LULUC)	Affected by Fire	Affected by Logging	Affected by other disturbances	TOTAL
Wet Evergreen Forest				0
Moist Evergreen Forest			1271	1,271
Moist Semi-deciduous SE Forest		1280	1280	2,561
Moist Semi-deciduous NW Forest		618	2449	3,067
Upland Evergreen Forest				0
Dry Semidecidouos (Fire Zone) Forest				0
Dry Semidecidouos (Inner Zone) Forest				0
Savannah Forest	6594	6594		13,188
Southern Marginal Forest				0
Croplands, Annual Crops				0
Croplands, Perennial Crops				0
Croplands, Fallow				0
Grasslands (Pasture / Savannahs / Shrublands)				0
Wetland				0
Settlement				0
Other Lands				0
TOTAL	6,594	8,492	5,000	20,085

DISTURBANCES

Period	Land Use and Land Use Change (LULUC) Vertical: Inicial Use Horizontal: Disturbance	Affected by Fire	Affected by Logging	Affected by other disturbances	TOTAL
2010-2011	Wet Evergreen Forest				0
	Moist Evergreen Forest		637		637
	Moist Semi-deciduous SE Forest		640	640	1,280
	Moist Semi-deciduous NW Forest		618		618
	Upland Evergreen Forest				0
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest	6594		6594	13,188
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	6,594	1,895	7,234	15,722
2009-2010	Wet Evergreen Forest			1212	1,212
	Moist Evergreen Forest		637		637
	Moist Semi-deciduous SE Forest			640	640
	Moist Semi-deciduous NW Forest		618	618	1,236
	Upland Evergreen Forest				0
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest				0
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	0	1,255	2,470	3,725
2008-2009	Wet Evergreen Forest				0
	Moist Evergreen Forest		1910	1907	3,818
	Moist Semi-deciduous SE Forest				0
	Moist Semi-deciduous NW Forest		618		618
	Upland Evergreen Forest		159	159	319
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest				0
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	0	2,687	2,067	4,754

DISTURBANCES

Period	Land Use and Land Use Change (LULUC) Vertical: Inicial Use Horizontal: Disturbance	Affected by Fire	Affected by Logging	Affected by other disturbances	TOTAL
2007-2008	Wet Evergreen Forest		606		606
	Moist Evergreen Forest		637	1271	1,907
	Moist Semi-deciduous SE Forest		640		640
	Moist Semi-deciduous NW Forest		1236		1,236
	Upland Evergreen Forest				0
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest				0
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	0	3,119	1,271	**4,390**
2006-2007	Wet Evergreen Forest				0
	Moist Evergreen Forest				0
	Moist Semi-deciduous SE Forest				0
	Moist Semi-deciduous NW Forest				0
	Upland Evergreen Forest		319		319
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest				0
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	0	319	0	**319**
2005-2006	Wet Evergreen Forest				0
	Moist Evergreen Forest			1271	1,271
	Moist Semi-deciduous SE Forest		1211		1,211
	Moist Semi-deciduous NW Forest		618	618	1,236
	Upland Evergreen Forest				0
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest				0
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	0	1,829	1,889	**3,717**

DISTURBANCES

Land Use and Land Use Change (LULUC)

Vertical: Inicial Use
Horizontal: Disturbance

Period	LULUC	Affected by Fire	Affected by Logging	Affected by other disturbances	TOTAL
2004-2005	Wet Evergreen Forest				0
	Moist Evergreen Forest				0
	Moist Semi-deciduous SE Forest				0
	Moist Semi-deciduous NW Forest				0
	Upland Evergreen Forest				0
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest				0
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	0	0	0	**0**
2003-2004	Wet Evergreen Forest				0
	Moist Evergreen Forest				0
	Moist Semi-deciduous SE Forest				0
	Moist Semi-deciduous NW Forest				0
	Upland Evergreen Forest				0
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest				0
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	0	0	0	**0**
2002-2003	Wet Evergreen Forest				0
	Moist Evergreen Forest				0
	Moist Semi-deciduous SE Forest				0
	Moist Semi-deciduous NW Forest				0
	Upland Evergreen Forest		159		159
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest				0
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	0	159	0	**159**

DISTURBANCES

Period	Land Use and Land Use Change (LULUC) Vertical: Inicial Use Horizontal: Disturbance	Affected by Fire	Affected by Logging	Affected by other disturbances	TOTAL
2001-2002	Wet Evergreen Forest				0
	Moist Evergreen Forest				0
	Moist Semi-deciduous SE Forest				0
	Moist Semi-deciduous NW Forest				0
	Upland Evergreen Forest				0
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest				0
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	0	0	0	**0**
2000 - 2001	Wet Evergreen Forest				0
	Moist Evergreen Forest				0
	Moist Semi-deciduous SE Forest				0
	Moist Semi-deciduous NW Forest				0
	Upland Evergreen Forest				0
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest		6594		6,594
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	0	6,594	0	**6,594**
2000	Wet Evergreen Forest				0
	Moist Evergreen Forest				0
	Moist Semi-deciduous SE Forest			2422	2,422
	Moist Semi-deciduous NW Forest			618	618
	Upland Evergreen Forest			159	159
	Dry Semidecidouos (Fire Zone) Forest				0
	Dry Semidecidouos (Inner Zone) Forest				0
	Savannah Forest				0
	Southern Marginal Forest				0
	Croplands, Annual Crops				0
	Croplands, Perennial Crops				0
	Croplands, Fallow				0
	Grasslands (Pasture / Savannahs / Shrublands)				0
	Wetland				0
	Settlement				0
	Other Lands				0
	TOTAL	0	0	3,199	**3,199**

Forest land converted to other land-use categories (deforestation)

This session provides the information and emission factors and parameters necessary to estimate emissions and removals for **land converted to another land-use categories (Deforestation)**. Equation 2.15 in the 2006 IPCC GLs, reproduced below, provides the basis for these estimations. For REDD+ purposes, the focus is on Forest land converted to other land-use categories.

Annual change in biomass carbon stocks on land converted to other land-use category (tier 2) (Equation 2.15, Ch2, V4)

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

Where:

ΔC_B = annual change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr^{-1}

ΔC_G = annual increase in carbon stocks in biomass due to growth on land converted to another land-use category, in tonnes C yr^{-1}

$\Delta C_{CONVERSION}$ = initial change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr^{-1}

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuelwood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1}

Annual increase in biomass carbon stocks on land converted to other land-use category (tier 2) (Equation 2.9, Ch2, V4)

Annual increase in carbon stocks in biomass due to land converted to forest lands was estimated following same methods as land remaining in the same category.

Initial change in biomass carbon stocks on land converted to another land category, $\Delta C_{CONVERSION}$ (Equation 2.16, Ch2, V4)

$$\Delta C_{CONVERSION} = \Sigma \{ (B_{AFTERi} - B_{BEFOREi}) \bullet \Delta A_{TO\_OTHERSi} \} \bullet CF$$

Where:

$\Delta C_{CONVERSION}$ = initial change in biomass carbon stocks on land converted to another land category, tonnes C yr^{-1}

B_{AFTERi} = biomass stocks on land type *i* immediately after the conversion, tonnes d.m. yr^{-1}

$B_{BEFOREi}$ = biomass stocks on land type *i* before the conversion, tonnes d.m. ha^{-1}

$\Delta A_{TO\_OTHERSi}$ = area of land use *i* converted to another land-use category in a certain year, ha yr^{-1}

CF = carbon fraction of dry matter, tonne C (tonnes d.m.)$^{-1}$

i **=** type of land use converted to another land-use category

The estimates for the parameters for Equation 2.16 above are provided below.

A - area of land use converted to another land-use category

The source of the areas of Forest land converted to other land-use categories, ΔA_{TO_OTHER}, is provided in Table 41. The same source is used to estimate the areas of other land-use categories converted to Forest land, to be addressed in sequence. Please refer to pivot table with area estimation for each land use conversion.

Table 40. Source of areas of land converted to and from Forest land.

A: area of land converted to and from Forest lands			
LU	Sub-Category	Source	Notes
F > No-F	Forest Lands > Non-Forest Lands	Collect Earth	Years 2000 – 2015
No F > F	Non-Forest Lands > Forest Lands	Collect Earth	Years 2000 – 2015

B_{AFTER} - biomass stocks on the land type immediately after the conversion:

Please refer to Table 21 for annual Gw values. These values will be allocated annually to each land use until maximum biomass stock is reached.

Notes:

- **For Cropland (annual crops):** According with the 2006 IPCC GLs, volume 4, chapter 5 (Cropland), page 5.26, at tier 1, carbon stocks in biomass immediately after conversion (B_{AFTER}) are assumed to be zero, since the land is cleared of all vegetation before planting crops.

- **For Wetlands:** For Wetlands, the 2006 IPCC GLS provides limited guidance for conversion to wetlands and does not provide explicit mention to B_{AFTER}, which is here also assumed to be equal to zero, based on the Tier 1 assumption in page 4.37 of the 2006 IPCC GLs that carbon stocks in litter and dead word pools in all non-forest-use categories are zero.

- **For Settlements:** According with the 2006 IPCC GLs, volume 4, chapter 8 (Settlements), page 8.18, "for Tier 1, in the initial year following conversion to the settlement land use, the most conservative approach is to set B_{AFTER} to zero, meaning that the process of development of settlements causes carbon stocks to be entirely depleted".

- **For Other Land:** According with the 2006 IPCC GLs, volume 4, chapter 9 (Settlements), page 9.4, "… in this case, B_{AFTER} in Equation 2.16 is set to zero by default. The default assumption for the Tier 1 calculation is that all carbon is biomass (less harvested wood products removed from the area) is released to the atmosphere immediately…". Tier 2 methods also assume that the carbon stock after conversion (B_{AFTER}) is zero.

B_{BEFORE}- biomass stocks on land before the conversion

Please refer to Table 34 for annual Bw values for each land use category and sub-category to be applied as biomass stock before the conversion.

Annual decrease in carbon stocks in biomass due to losses, ΔC_L (Equation 2.11-2.14, Ch2, V4)

The annual decrease in C stocks in biomass due to losses on converted land (wood removals or fellings, fuelwood collection, and disturbances) was estimated using Equations 2.11 to 2.14 in the 2006 IPCC GLs, as described above for land remaining in a same land-use category.

Change in dead organic matter carbon stock in land remaining in the same land-use category

Change in dead organic matter carbon stock in land remaining in the same category

The Tier 1 assumption for both deadwood and litter pools for all land-use categories is that their stocks are not changing over time if the land remains in the same land-use category. Thus, the carbon in biomass killed during a disturbance or management event (less removal of harvested wood products) is assumed to be released entirely to the atmosphere in the year of the event.

Change in dead organic matter in carbon stock in land converted to a new land category

The changes in carbon stock in the dead organic matter pool (litter and deadwood pools) are estimated using Equation 2.23 in the 2006 IPCC GLs, reproduced below.

Land converted from forest to another land-use category (Equation 2.23, Ch2, V4)

$$\Delta C_{DOM} = [(C_n - C_o) \text{ x } A_{on}] / T_{on}$$

Where:

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter, tonnes C ha^{-1}
C_o = dead wood/litter stock, under the old land-use category, tonnes C ha^{-1}
C_n = dead wood/litter stock, under the new land-use category, tonnes C ha^{-1}
A_{on} = area undergoing conversion from old to new land-use category, ha
T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses.

Table 42 provides the estimates of the weighted average carbon stocks in litter and deadwood. Table 4.8 in the Report on Mapping of the Forest Cover and Carbon Stock in Ghana (FPP) provides estimates for litter and dead wood for open and closed forests for all vegetation zones, which are reproduced in Table 43 and Table 44 for litter and deadwood, respectively, with the information for the calculation of the weighted averages. The standard deviations for each estimated value for open and closed forests in each vegetation zone are also provided.

Table 41. Weighted averages of carbon stocks in litter and deadwood for each vegetation zone, tonnes C yr^{-1}.

DOM: weighted carbon stocks in litter and dead wood, tonnes C ha^{1}						
LU	Sub-Category	Value Litter	St. Dev	Value Deadwood	St. Dev.	Notes
F	Wet Evergreen	2.79	9.75	27.19	56.07	Since there was no value for open forest in the FPP, the default values of 4.80 tC ha^{-1} and 14.8 tC ha^{-1} for dead wood in the 2019 Refinement, Table 2.2 were used for litter and dead wood, respectively, for Tropical Rainforest, all vegetation types.
	Moist Evergreen	2.71	21.02	787.26	43.55	
	Moist Semideciduous SE	2.44	28.52	55.96	58.57	
	Moist Semideciduous NW	2.18	11.69	109.68	37.67	
	Upland Evergreen	1.36	23.17	240.86	109.87	
	Dry Semideciduous (Fire Zone)	2.38	NA	8.82	0.63	Since there was no value for closed forest in the FPP, the default values of 2.40 tC ha^{-1} and 9.00 tC ha^{-1} for dead wood in the 2019 Refinement, Table 2.2 were used for litter and dead wood, respectively, for Tropical Dry Forest, all vegetation types.
	Dry Semideciduous (Inner)	1.41	NA	6.15	0.00	
	Savannah	2.31	NA	12.53	2.03	Since there was no value for closed forest in the FPP, the default values of 2.40 tC ha^{-1} and 9.00 tC ha^{-1} for dead wood in the 2019 Refinement, Table 2.2 were used for litter and dead wood, respectively, all vegetation types.
	Southern Marginal	1.71	54.78	1.71	76.28	

C	Annual crops	NA	NA			
	Perennial crops	NA	NA			
	Fallow Lands	NA	NA			
G	Grasslands	NA	NA			
W	Wetlands	0				NA
S	Settlements	0				NA
O	Other lands	0				NA

DOM- Forest lands

Table 42. Estimates of litter (LI) by vegetation zone and forest type (tC ha⁻¹) and weighted average for each vegetation zone.

Vegetation Zone	Forest Type	Litter (tC ha-1)	Standard Deviation	Source
Wet Evergreen (WETVER)	Open	4.80	NA (n=0)	2019 Refinement, Table 2.2 % OPEN = 2.78
	Closed	2.73	(n=5); SD = 10.03	FPP, Table 4.8 % CLOSED = 97.22
	Weighted Average	2.79		
Moist Evergreen (MEVER)	Open	1.09	(n=6); SD = 21.08	FPP, Table 4.8 % OPEN = 1.09
	Closed	2.73	(n=30); SD = 21.02	FPP, Table 4.8 % CLOSED = 98.91
	Weighted Average	2.71		
Moist Semi-deciduous SE (MSEMSE)	Open	2.18	(n=7); SD = 16.94	FPP, Table 4.8 % OPEN = 5.00
	Closed	2.45	(n=9) SD = 29.12	FPP, Table 4.8 % CLOSED = 95.00
	Weighted Average	2,44		
Moist Semi-deciduous NW (MSEMNW)	Open	2.18	(n=24) SD = 17.74	FPP, Table 4.8 % OPEN = 4.11
	Closed	2.18	(n=45) SD = 11.43	FPP, Table 4.8 % CLOSED = 95.89
	Weighted Average	2.18		
Upland Evergreen (UPEVER)	Open	1.09	(n=6) SD = 29.72	FPP, Table 4.8 % OPEN = 3.59
	Closed	1.36	(n=15) SD = 22.93	FPP, Table 4.8 % CLOSED = 96.41
	Weighted Average	1.35		
Dry Semideciduous (Fire Zone) Forest	Open	1.64	(n=11) SD = 0.00	FPP, Table 4.8 % OPEN = 3.08
	Closed	2.40	(n=1) SD = NE	2019 Refinement, Table 2.2

				% CLOSED = 96.92
	Weighted Average	2.38		
Dry Semideciduous (Inner Zone) Forest	Open	1.91	(n=9) SD = 18.0	FPP, Table 4.8 % OPEN = 8.11
	Closed	1.36	(n=1) SD = NE	FPP, Table 4.8 % CLOSED = 91.89
	Weighted Average	1.41		
Savannah Forest	Open	1.64	(n=12) SD = 4.80	FPP, Table 4.8 % OPEN = 12.09
	Closed	2.40	(n=0) SD = NE	2019 Refinement, Table 2.2 % CLOSED = 87.91
	Weighted Average	2.31		
Southern Marginal Forest	Open	0.55	(n=4) SD = 29.92	FPP, Table 4.8 % OPEN = 28.57
	Closed	2.18	(n=3) SD = 64.72	FPP, Table 4.8 % CLOSED = 71.43
	Weighted Average	1.71		

Table 43. Estimates of deadwood (DW) by vegetation zone and forest type (tC ha^{-1}) and weighted average for each vegetation zone.

Vegetation Zone	Forest Type	Deadwood (tC ha-$^{1)}$	Standard Deviation	Source
Wet Evergreen (WETVER)	Open	14.80	NE (n=0)	2019 Refinement, Table 2.2 % OPEN = 2.78
	Closed	27.55	(n=5); SD = 57.68	FPP, Table 4.8 % CLOSED = 97.22
	Weighted Average	27.19		
Moist Evergreen (MEVER)	Open	109.36	(n=6); SD = 8.12	FPP, Table 4.8 % OPEN = 1.09
	Closed	794.73	(n=30); SD = 43.94	FPP, Table 4.8 % CLOSED = 98.91
	Weighted Average	787.26		
Moist Semi-deciduous SE (MSEMSE)	Open	57.00	(n=7); SD = 58.52	FPP, Table 4.8 % OPEN = 5.00
	Closed	55.91	(n=9) SD = 58.88	FPP, Table 4.8 % CLOSED = 95.00
	Weighted Average	55.96		
Moist Semi-deciduous NW (MSEMNW)	Open	129.82	(n=24) SD = 58.54	FPP, Table 4.8 % OPEN = 4.11
	Closed	108.82	(n=45) SD = 36.77	FPP, Table 4.8 % CLOSED = 95.89
	Weighted Average	109.68		

Upland Evergreen (UPEVER)	Open	7.64	(n=6) SD = 50.13	FPP, Table 4.8 % OPEN = 3.59
	Closed	249.55	(n=15) SD = 112.09	FPP, Table 4.8 % CLOSED = 96.41
	Weighted Average	240.86		
Dry Semideciduous (Fire Zone) Forest	Open	3.00	(n=11) SD = NE	FPP, Table 4.8 % OPEN = 3.08
	Closed	9.00	(n=1) SD = NE	2019 Refinement, Table 2.2 % CLOSED = 96.92
	Weighted Average	8.81		
Dry Semideciduous (Inner Zone) Forest	Open	7.91	(n=9) SD = 20.30	FPP, Table 4.8 % OPEN = 8.11
	Closed	6.00	(n=1) SD = NE	FPP, Table 4.8 % CLOSED = 91.89
	Weighted Average	6.15		
Savannah Forest	Open	38.18	(n=12) SD = 16.79	FPP, Table 4.8 % OPEN = 12.09
	Closed	9.00	(n=0) SD = NE	2019 Refinement, Table 2.2 % CLOSED = 87.91
	Weighted Average	12.53		
Southern Marginal Forest	Open	0.55	(n=4) SD = 67.04	FPP, Table 4.8 % OPEN = 28.57
	Closed	2.18	(n=3) SD = 79.97	FPP, Table 4.8 % CLOSED = 71.43
	Weighted Average	1.71		

DOM- Cropland

The IPCC 2019 Refinement, page 5.39, acknowledges that there is insufficient information to provide a default approach with default parameters to estimate carbon stock change in dead organic matter (DOM) pools**,** it is assumed that there will be no DOM in Cropland. In addition, the methodology in the 2019 Refinement for Cropland considers only carbon stock change in aboveground biomass since limited data are available on belowground carbon stocks in perennial Cropland.

DOM- Grassland

The 2006 IPCC GLs, volume 4, chapter 6, section 6.3.2.4 indicates that for tier 1 there is no dead wood or litter that remains or accumulates in Land converted to Grassland.

9. Historical forest-related GHG emissions and removals

Annual GHG emission and removals were estimated for the period 2001 – 2015. These GHG emissions and removals are related to Forest land remaining Forest land, and Forest land converted to and from other land-use categories.

These estimations indicate that the average net emissions from deforestation (same as from Forest land converted to other land-use categories) from 2001 to 2015 total 2,302,065 t CO_2-e. Forest land that was affected by some sort of disturbance has an average net emission of 151,652 t CO_2-e. Removals due to enhancements of forest carbon stocks, (same as for Land converted to Forest land) average -927,259 t CO_2-e (Figure 23). Deforestation therefore accounts for the highest emissions in Ghana. The main driver of deforestation in Ghana is agriculture (conversion of Forest land to Cropland, Table 46). Ghana's REDD Strategy, however, outlines a programme that seeks to halt expansionist agriculture production (mainly cocoa) into new forest frontiers.

Table 44 Historical GHG emission and removals 2001 - 2015 [t CO_2-e].

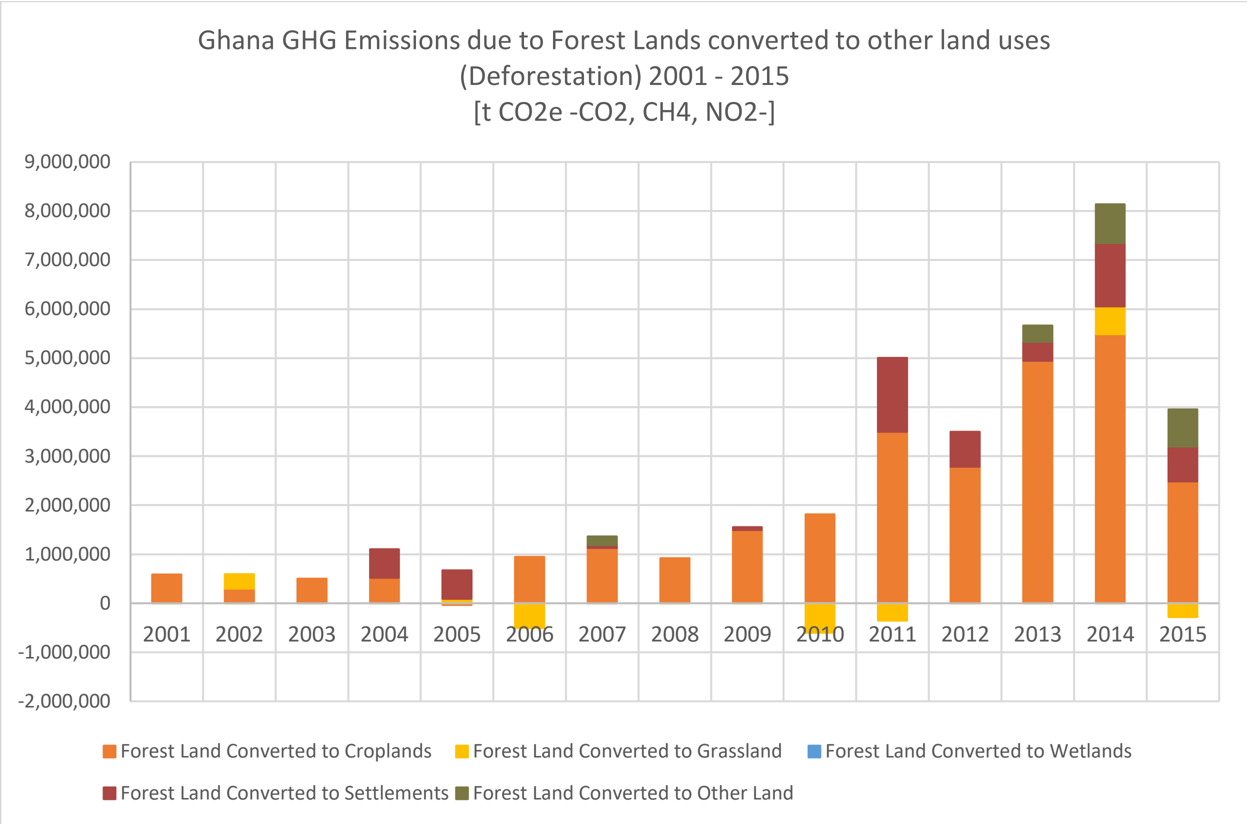
			Yr 2000 considers Land Use only, not LU changes.	Historical GHG emissions and Removals [t CO2-eq] [CO2, CH4, N2O]												
Associated	**Source Category**	**Gases**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	
Deforestation	Forest Land Converted to Croplands	CO2-eq	0	586,448	302,105	500,749	522,740	-31,112	942,032	1,128,159	917,219	1,494,743	1,813,898	3,496,351	2,78
	Forest Land Converted to Grassland	CO2-eq	0	0	292,711	0	0	93,214	-504,280	0	0	0	-599,333	-355,159	
	Forest Land Converted to Wetlands	CO2-eq	0	0	0	0	0	0	0	0	0	0	0	0	
	Forest Land Converted to Settlements	CO2-eq	0	0	0	0	581,114	576,354	0	55,340	0	55,340	0	1,511,534	71
	Forest Land Converted to Other Land	CO2-eq	0	0	0	0	0	0	0	178,951	0	0	0	0	
	Total emissions from Forest lands converted to other lands	**CO2-eq**	**0**	**586,448**	**594,817**	**500,749**	**1,103,855**	**638,456**	**437,752**	**1,362,451**	**917,219**	**1,550,083**	**1,214,565**	**4,652,725**	**3,49**
Degradation	**Logging**	CO2-eq	0	0	-26,750	-26,750	-29,517	-29,517	158,621	-69,911	295,381	-28,372	-56,255	90,687	-9
	Other disturbance	CO2-eq	423,396	-71,842	-71,842	-71,842	-71,842	-71,842	235,940	-115,811	148,708	397,058	455,532	292,670	43
	Fire	CO2-eq	0	0	0	0	0	0	0	0	0	0	0	320,997	-4
	Total emissions and removals from Forest Land Remaining Forest Land (Disturbed)	**CO2-eq**	**423,396**	**-71,842**	**-98,591**	**-98,591**	**-101,358**	**-101,358**	**394,562**	**-185,722**	**444,089**	**368,686**	**399,277**	**704,354**	**29**
Enhacement of C Stocks	**Total removals fom Land Converted to Forest Land**	CO2-eq	0	0	0	0	0	0	0	-18,935	-423,634	-1,023,301	-577,412	-864,400	-1,59
Historical Emissions (+) and Removals (-) i[t CO2 eq] 2001-2015				**514,607**	**496,225**	**402,158**	**1,002,496**	**537,097**	**832,314**	**1,157,793**	**937,674**	**895,469**	**1,036,431**	**4,492,680**	**2,18**

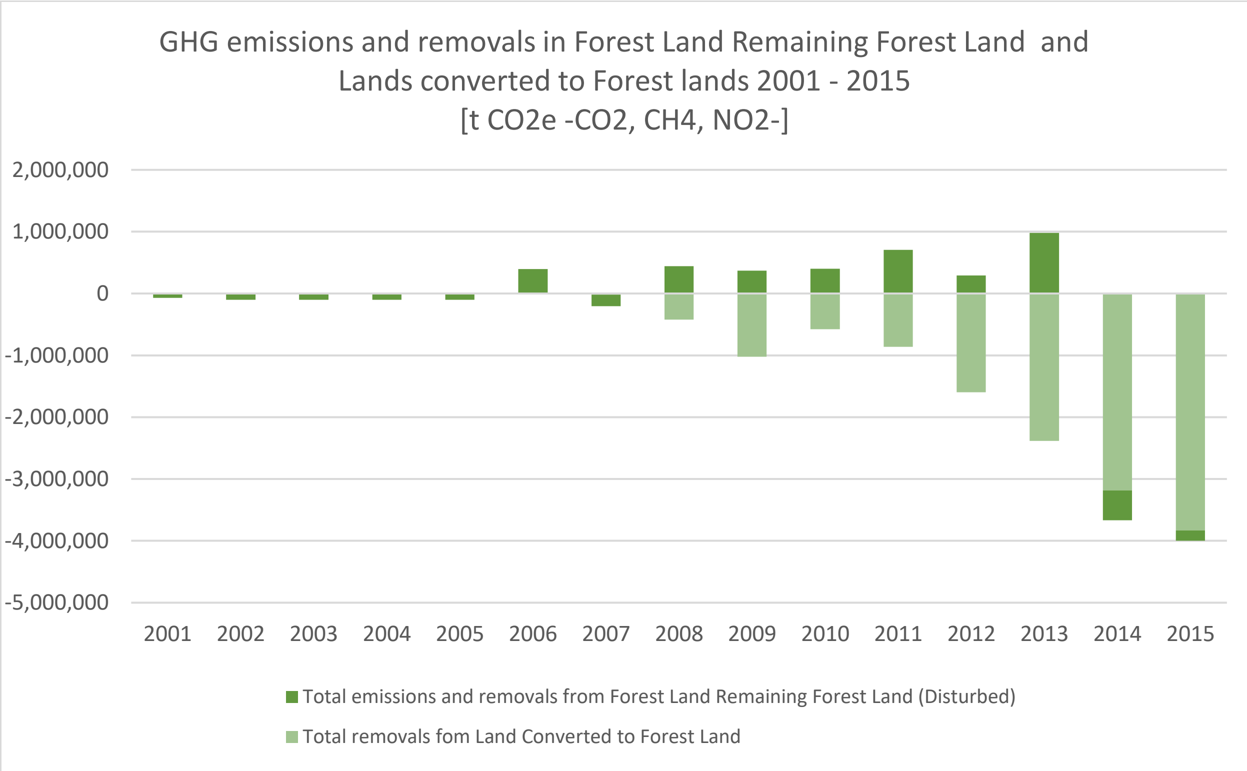
Table 45 Average historical GHG emission and removals projected to 2016 - 2019 [t CO_2-e]

			FOREST REFERENCE EMISSIONS LEVEL (Historical Average of GHG emissions (+) and removals (-)) [t CO2-eq] [CO2,CH4, N2O]			
Associated REDD+ Activity	**Source Category**	**Gases**	**2016**	**2017**	**2018**	**2019**
Deforestation	Forest Land Converted to Croplands	CO2-eq	1,825,582	1,825,582	1,825,582	1,825,582
	Forest Land Converted to Grassland	CO2-eq	-52,618	-52,618	-52,618	-52,618
	Forest Land Converted to Wetlands	CO2-eq	0	0	0	0
	Forest Land Converted to Settlements	CO2-eq	392,046	392,046	392,046	392,046
	Forest Land Converted to Other Land	CO2-eq	137,055	137,055	137,055	137,055
	Total emissions from Forest lands converted to other lands	**CO2-eq**	**2,302,065**	**2,302,065**	**2,302,065**	**2,302,065**
Degradation	**Logging**	CO2-eq	-7,482	-7,482	-7,482	-7,482
	Other disturbance	CO2-eq	158,395	158,395	158,395	158,395
	Fire	CO2-eq	738	738	738	738
	Total emissions and removals from Forest Land Remaining Forest Land (Disturbed)	**CO2-eq**	**151,652**	**151,652**	**151,652**	**151,652**
	Total removals fom Land Converted to Forest Land	CO2-eq	**-927,259**	**-927,259**	**-927,259**	**-927,259**
FREL (projected GHG emissions (+) and removals (-)) [t CO2-eq] [CO2,CH4, N2O] 2016-2019			**1,526,457**	**1,526,457**	**1,526,457**	**1,526,457**

Based on the average GHG emissions from deforestation, from forest degradation and from the enhancement of forest carbon stocks, in the period 2001 – 2015, a single value is defined for the FREL/FRL, defined as the sum of the three averages. The FREL/FRL is then 1,526,457 tCO_2-e and is taken as the benchmark to assess the performance of the implementation of the three REDD+ activities selected: Reducing emissions from Deforestation, Reducing Emissions from Forest Degradation and Enhancement of Carbon Stocks at national level.

Figure 18 Ghana GHG Emissions and removals in Forest land remaining and converted





9.1 Forest lands 2001-2015

The Forest Management regime in Ghana where over a tenth of the total land area are managed under forest reservation, has significantly contributed to the retention of Forest land over the years. Timber exploitation in Ghana over the centuries has resulted in a virtual total loss of forest outside reserved areas. That not withstanding, over 96% of Forest land was retained during the reference period (5,508,240 ha of forest remained by 2015, compared to the initial 5,700,827 in year 2000, representing and annual loss of 0.33% and a cumulative lost of 3.44 % in 15 years).

Table 46. Total Forest Land remaining Forest Land 2000 - 2015 (Ha).

Year	Total Forest Land Remaining Forest Land (ha) (Net values)	Annual difference (ha)	Annual % loss (%)	Cumulative % loss (%)
2000	5,700,827			
2001	5,687,639	13,188	-0.23%	
2002	5,679,788	7,852	-0.14%	-0.37%
2003	5,677,889	1,898	-0.03%	-0.40%
2004	5,664,065	13,824	-0.24%	-0.65%
2005	5,655,023	9,042	-0.16%	-0.81%
2006	5,650,409	4,615	-0.08%	-0.89%
2007	5,640,350	10,059	-0.18%	-1.07%
2008	5,637,222	3,128	-0.06%	-1.12%
2009	5,627,938	9,284	-0.16%	-1.29%
2010	5,607,331	20,607	-0.37%	-1.66%
2011	5,557,858	49,473	-0.89%	-2.55%
2012	5,555,492	2,366	-0.04%	-2.59%
2013	5,546,505	8,987	-0.16%	-2.75%
2014	5,513,955	32,550	-0.59%	-3.34%
2015	5,508,240	5,714	-0.10%	-3.44%

Some vegetation zones were more affected, such as can be seen from comparison of Tables 48 – 56.

Table 47. Wet Evergreen annual differences (ha).

Wet Evergreen Forest (ha)	*Annual difference (ha)*	*%*
285,577		
285,577	0	0.00%
285,577	0	0.00%
285,577	0	0.00%
285,577	0	0.00%
284,365	1,212	-0.43%
284,365	0	0.00%
284,365	0	0.00%
284,365	0	0.00%
284,365	0	0.00%
283,758	606	-0.21%
283,758	0	0.00%
283,758	0	0.00%
281,334	2,425	-0.86%
280,727	606	-0.22%
279,515	1,213	-0.43%

Table 48. Moist Evergreen annual difference (ha).

Moist Evergreen Forest (ha)	Annual difference (ha)	%
647,910		
647,910	0	0.00%
647,910	0	0.00%
647,910	0	0.00%
647,273	637	-0.10%
647,273	0	0.00%
646,636	637	-0.10%
645,366	1,271	-0.20%
644,095	1,271	-0.20%
643,461	634	-0.10%
643,461	0	0.00%
639,012	4,449	-0.70%
637,739	1,273	-0.20%
632,019	5,720	-0.90%
625,029	6,990	-1.12%
620,574	4,454	-0.72%

Table 49. Moist Semi-deciduous – SE annual difference (ha).

Moist Semi-deciduous SE Forest (ha)	*Annual difference (ha)*	*%*
414,018		
414,018	0	0.00%
413,378	640	-0.15%
412,097	1,280	-0.31%
412,097	0	0.00%
412,097	0	0.00%
408,897	3,201	-0.78%
408,256	640	-0.16%
407,616	640	-0.16%
406,976	640	-0.16%
402,565	4,412	-1.10%
400,004	2,561	-0.64%
394,312	5,692	-1.44%
390,541	3,771	-0.97%
383,777	6,764	-1.76%
383,137	640	-0.17%

Table 50. Moist Semi-deciduous – NW annual difference (ha)

Moist Semi-deciduous NW Forest (ha)	*Annual difference (ha)*	*%*
456,240		
456,240	0	0.00%
455,622	618	-0.14%
455,004	618	-0.14%
455,004	0	0.00%
453,768	1,236	-0.27%
453,150	618	-0.14%
451,915	1,236	-0.27%
450,061	1,854	-0.41%
448,230	1,831	-0.41%
446,399	1,831	-0.41%
437,246	9,154	-2.09%
435,392	1,854	-0.43%
431,090	4,302	-1.00%
426,169	4,920	-1.15%
421,867	4,302	-1.02%

Table 51. Upland Evergreen Annual difference (ha).

Upland Evergreen Forest (ha)	Annual difference (ha)	%
33,132		
33,132	0	0.00%
33,132	0	0.00%
33,132	0	0.00%
33,132	0	0.00%
33,132	0	0.00%
32,973	159	-0.48%
32,654	319	-0.98%
32,654	0	0.00%
32,495	159	-0.49%
32,495	0	0.00%
32,177	319	-0.99%
32,017	159	-0.50%
31,380	637	-2.03%
31,380	0	0.00%
30,902	478	-1.55%

Table 52. Dry Semideciduous (fire zone) annual difference (ha).

Dry Semideciduous (Fire Zone) Forest (ha)	Annual difference (ha)	%
507,720		
507,720	0	0.00%
507,720	0	0.00%
507,720	0	0.00%
507,720	0	0.00%
507,720	0	0.00%
507,720	0	0.00%
507,720	0	0.00%
507,720	0	0.00%
507,720	0	0.00%
507,720	0	0.00%
507,720	0	0.00%
507,720	0	0.00%
507,720	0	0.00%
506,440	1,280	-0.25%
513,034	-6,594	1.29%

Table 53. Dry Semidecidouos (inner zone) annual difference (ha).

Dry Semideciduous (Inner Zone) Forest (ha)	Annual difference (ha)	%
303,313		
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%
303,313	0	0.00%

Table 54. Savannah annual difference (ha).

Savannah Forest (ha)	Annual difference (ha)	%
2,993,572		
2,980,385	13,188	-0.44%
2,973,791	6,594	-0.22%
2,973,791	0	0.00%
2,967,197	6,594	-0.22%
2,960,603	6,594	-0.22%
2,960,603	0	0.00%
2,954,010	6,594	-0.22%
2,954,010	0	0.00%
2,940,822	13,188	-0.45%
2,934,228	6,594	-0.22%
2,894,666	39,563	-1.37%
2,894,666	0	0.00%
2,901,259	-6,594	0.23%
2,888,072	13,188	-0.46%
2,888,072	0	0.00%

Table 55. Southern Marginal annual difference (ha).

Southern Marginal Forest (ha)	*Annual difference (ha)*	*%*
59,344		
59,344	13,188	-0.44%
59,344	6,594	-0.22%
59,344	0	0.00%
52,750	6,594	-0.22%
52,750	6,594	-0.22%
52,750	0	0.00%
52,750	6,594	-0.22%
52,750	0	0.00%
52,750	13,188	-0.45%
52,750	6,594	-0.22%
52,750	39,563	-1.37%
52,750	0	0.00%
52,750	-6,594	0.23%
52,750	13,188	-0.46%
46,156	0	0.00%

9.2 Deforestation 2001-2015

This assessment indicates that in the last 15 years, about 275,107 ha of Forest land have been cleared and converted to other land use. This represents 0.34% of forest loss in 15 years. The highest annual deforested area is 56,685 ha in 2011.

Empirically, this conversion is usually triggered as a result of continuous in shift agricultural activities that result into frequent clearing of the forest for new farmlands to farm. Beyond 2011, conversion of forest to other land use marginally increased and this could be linked to a rise in small scale gold mining in Ghana some of which were illegal. However national mitigation efforts by the Government of Ghana (including Inter-Ministerial Task Force from 2012 and Operation Vanguard in 2017) helped curtail the situation.

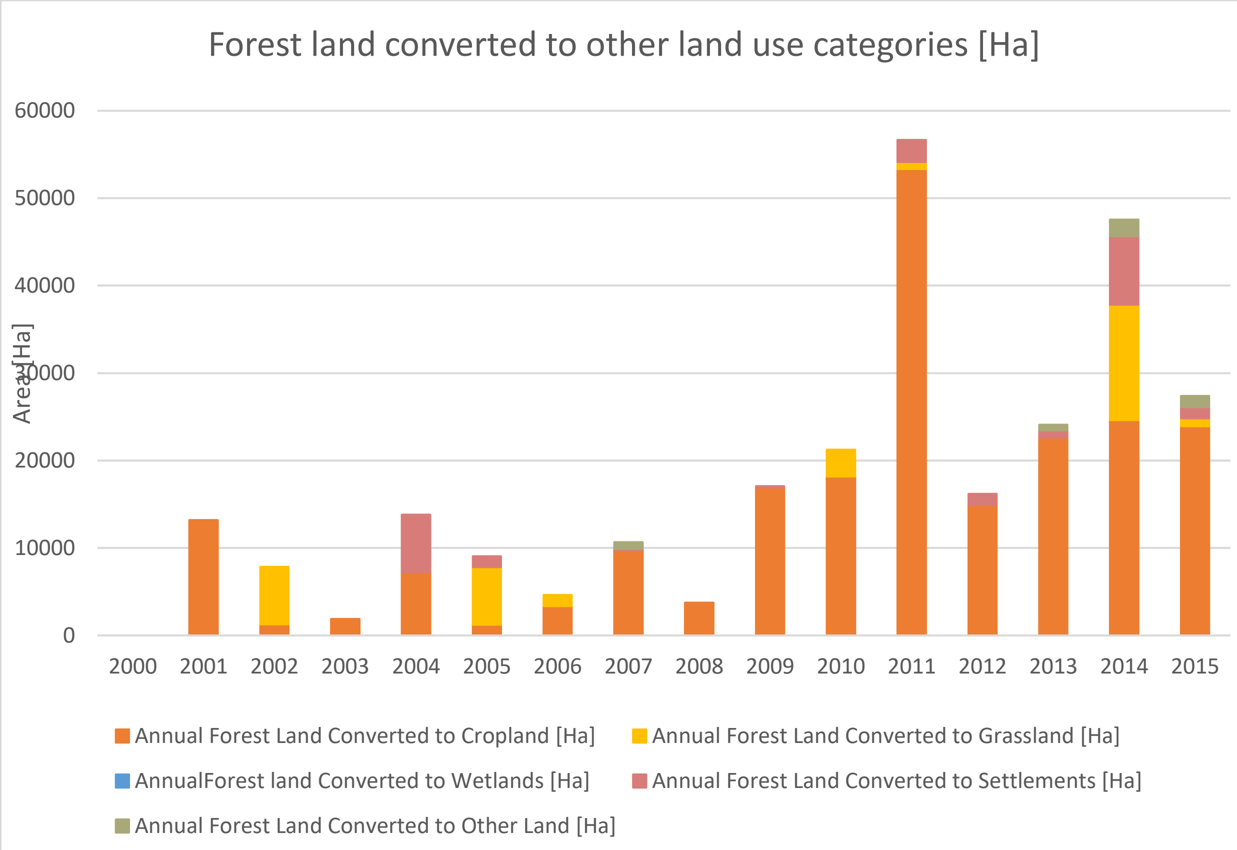
Table 56. Annual areas of Forest Land converted to other land-use categories (ha).

Year	Annual Forest Land Converted to Cropland (ha)	Annual Forest Land Converted to Grassland (ha)	Annual Forest land Converted to Wetlands (ha)	Annual Forest Land Converted to Settlements (ha)	Annual Forest Land Converted to Other Land (ha)	Total Annual F> conversion (ha)	% Total Annual F> conversion (ha)
2000	0	0	0	0	0	0	
2001	13188	0	0	0	0	13,188	0.23%
2002	1258	6594	0	0	0	7,852	0.14%
2003	1898	0	0	0	0	1,898	0.03%
2004	7231	0	0	6594	0	13,824	0.24%
2005	1236	6594	0	1212	0	9,042	0.16%
2006	3334	1280	0	0	0	4,615	0.08%
2007	9740	0	0	159	777	10,677	0.19%
2008	3765	0	0	0	0	3,765	0.07%
2009	16929	0	0	159	0	17,088	0.30%
2010	18183	3064	0	0	0	21,247	0.38%
2011	53347	796	0	2541	0	56,685	1.02%
2012	14913	0	0	1277	0	16,190	0.29%
2013	22646	0	0	799	640	24,086	0.43%
2014	24617	13188	0	7864	1898	47,567	0.86%
2015	23912	925	0	1277	1271	27,384	0.50%

Table 57. Cummulative areas of Forest Land converted to other land uses (ha)

Year	Cumulative Forest Land Converted to Cropland (ha)	Cumulative Forest Land Converted to Grassland (ha)	Cumulative Forest land Converted to Wetlands (ha)	Cumulative Forest Land Converted to Settlements (ha)	Cumulative Forest Land Converted to Other Land (ha)	Total Cumulative F> conversion (ha)
2000	0	0	0	0	0	0
2001	13,188	0	0	0	0	13,188
2002	14,446	6,594	0	0	0	21,039
2003	16,344	6,594	0	0	0	22,938
2004	23,574	6,594	0	6,594	0	36,762
2005	24,810	13,188	0	7,806	0	45,803
2006	28,144	14,468	0	7,806	0	50,418
2007	37,885	14,468	0	7,965	777	61,095
2008	41,649	14,468	0	7,965	777	64,860
2009	58,579	14,468	0	8,124	777	81,948
2010	76,762	17,532	0	8,124	777	103,195
2011	130,109	18,328	0	10,666	777	159,880
2012	145,022	18,328	0	11,943	777	176,070
2013	167,668	18,328	0	12,742	1,417	200,156
2014	192,285	31,515	0	20,607	3,316	247,722
2015	216,197	32,440	0	21,884	4,586	275,107

Figure 19 Forest land converted to other land use categories



fig(19), illustrates a spike in year 2011 as a result of conversion of FL to CL which affirms that, Ghana is loosing most of its forest lands to agricultural lands.

9.2 Forest degradation 2001-2015

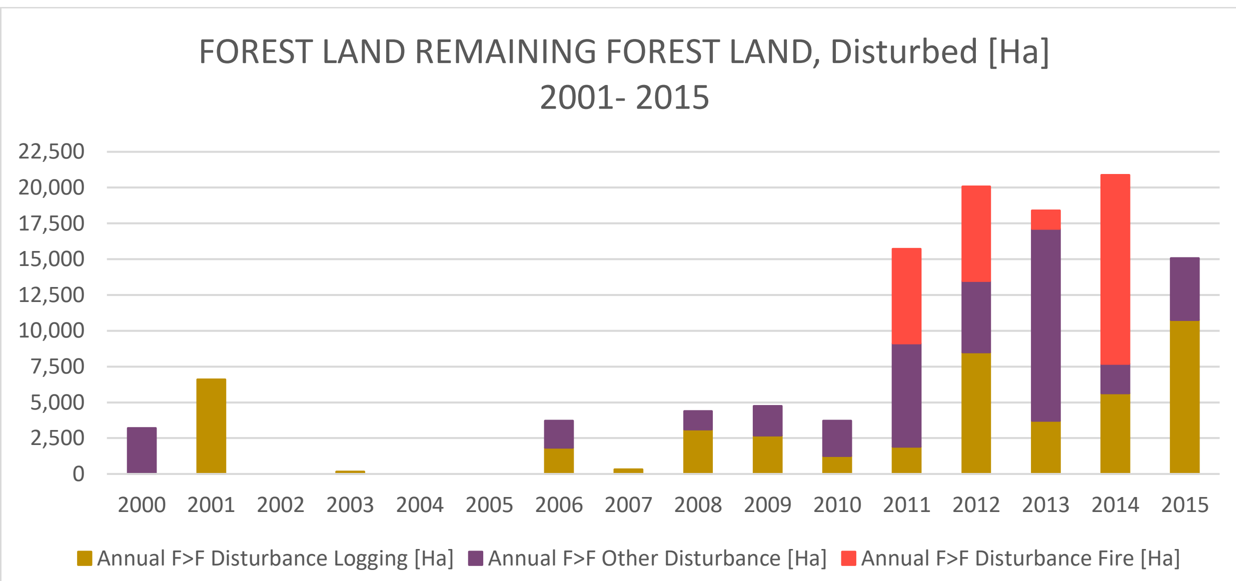
A total of 117,014 ha of Forest was disturbed (degraded) between 2001 and 2015. Annual area of forest degradation is shown in Figure xxx. The largest forest degradation was recorded in 2014 with 20,873 ha.

Table 58. Annual and Cumulative areas of Forest Degradation (ha).

Year	Annual F>F Disturbance Logging (ha)	Annual F>F Other Disturbance (ha)	Annual F>F Disturbance Fire (ha)	Total Annual F>F Disturbance (ha)	Cumulative F>F Disturbance Logging (ha)	Cumulative F>F Other Disturbance (ha)	Cumulative F>F Disturbance Fire (ha)	Total Cumulative F>F Disturbance (ha)
2000	0	3,199	0	3,199	0	3,199	0	3,199

2001	6,594	0	0	6,594	6,594	3,199	0	9,793
2002	0	0	0	0	6,594	3,199	0	9,793
2003	159	0	0	159	6,753	3,199	0	9,952
2004	0	0	0	0	6,753	3,199	0	9,952
2005	0	0	0	0	6,753	3,199	0	9,952
2006	1,829	1,889	0	3,717	8,582	5,088	0	13,669
2007	319	0	0	319	8,900	5,088	0	13,988
2008	3,119	1,271	0	4,390	12,019	6,358	0	18,378
2009	2,687	2,067	0	4,754	14,707	8,425	0	23,132
2010	1,255	2,470	0	3,725	15,962	10,895	0	26,857
2011	1,895	7,234	6,594	15,722	17,856	18,129	6,594	42,579
2012	8,492	5,000	6,594	20,085	26,348	23,129	13,188	62,665
2013	3,726	13,394	1,280	18,400	30,074	36,523	14,468	81,064
2014	5,635	2,051	13,188	20,873	35,709	38,573	27,655	101,938
2015	10,761	4,315	0	15,076	46,470	42,888	27,655	117,014

Figure 20 Forest Land remaining forest land, disturbed



Lands converted to Forest 2001-2015

Table 59. Annual Land converted to Forest Land (2001 – 2015) (ha).

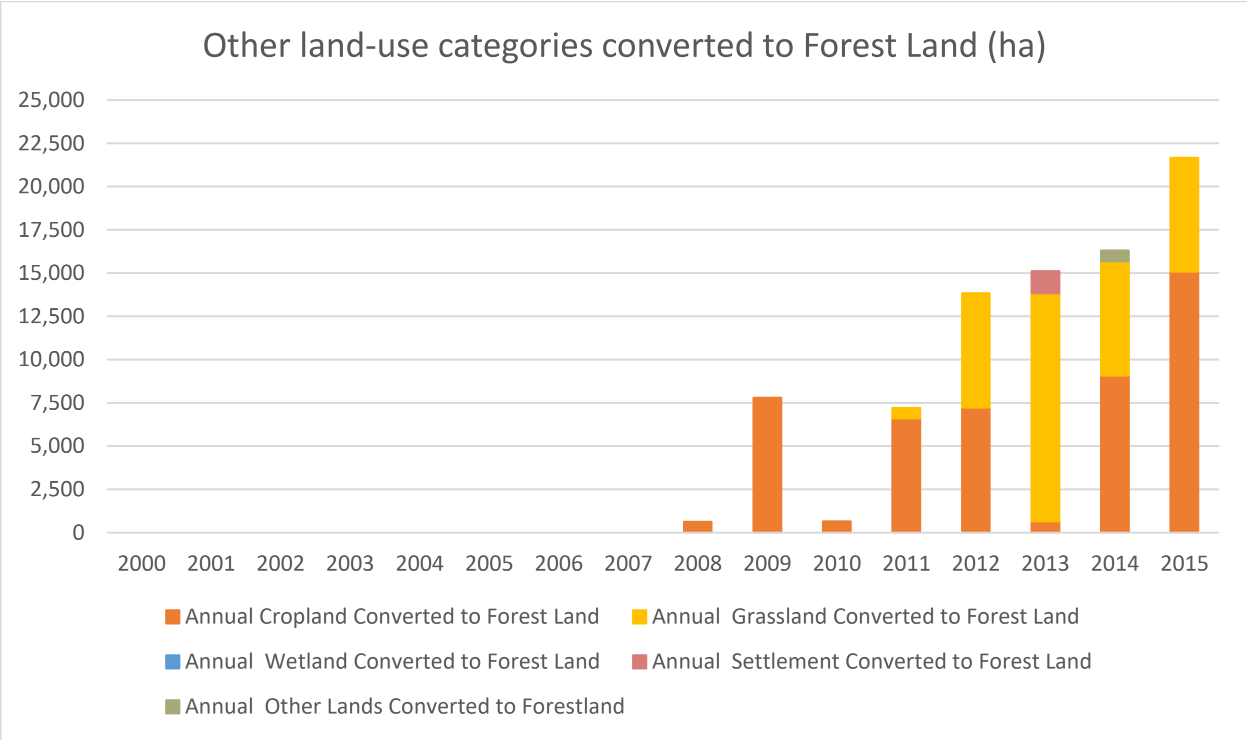
Year	Annual Cropland Converted to Forest Land (ha)	Annual Grassland Converted to Forest Land (ha)	Annual Wetland Converted to Forest Land (ha)	Annual Settlement Converted to Forest Land (ha)	Annual Other Lands Converted to Forestland (ha)

2000	0	0	0	0	0
2001	0	0	0	0	0
2002	0	0	0	0	0
2003	0	0	0	0	0
2004	0	0	0	0	0
2005	0	0	0	0	0
2006	0	0	0	0	0
2007	0	0	0	0	0
2008	637	0	0	0	0
2009	7805	0	0	0	0
2010	640	0	0	0	0
2011	6594	618	0	0	0
2012	7231	6594	0	0	0
2013	640	13188	0	1271	0
2014	9085	6594	0	0	618
2015	15076	6594	0	0	0

Table 60. Cumulative area of Land converted to Forest Land (2001 – 2015) (ha).

Year	Cumulative Cropland Converted to Forest Land (ha)	Cumulative Grassland Converted to Forest Land (ha)	Cumulative Wetland Converted to Forest Land (ha)	Cumulative Settlement Converted to Forest Land (ha)	Cumulative Other Lands Converted to Forest Land (ha)	Total cumulative conversion > F (ha)
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	0	0	0	0	0	0
2003	0	0	0	0	0	0
2004	0	0	0	0	0	0
2005	0	0	0	0	0	0
2006	0	0	0	0	0	0
2007	0	0	0	0	0	0
2008	637	0	0	0	0	637
2009	8441	0	0	0	0	8,441
2010	9082	0	0	0	0	9,082
2011	16293	0	0	0	0	16,293
2012	22269	6594	0	0	0	28,863
2013	30117	19781	0	1271	0	51,170
2014	30143	26375	0	1271	618	58,407
2015	45219	32969	0	1271	618	80,077

Figure 21 Other land use categories converted to Forest land.



10. INFORMATION ON QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) PROCEDURES

10.1 QA/QC of the activity data LULUC collection

It is good practice to implement Quality Assurance / Quality Control (QA/QC) procedures in the phases of design, implementation and analysis. QA/QC procedures contribute to improve transparency, consistency, comparability, and accuracy (IPCC, 2006). Before the data collection started, experts jointly revised the classification hierarchy and reviewed a number of sampling plots together to enhance internal consistency.

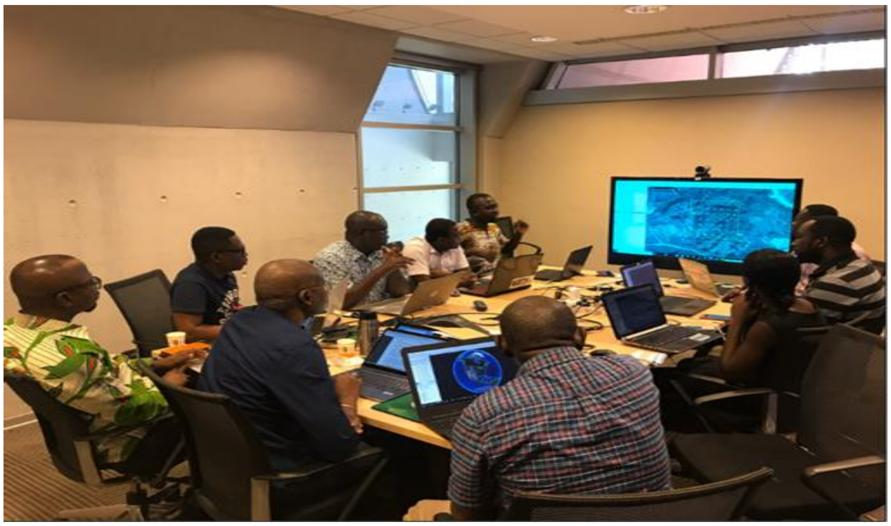


Figure 22. Ghana team doing QA/QC during data collection

In order for Ghana to avoid any form of enormous and misleading results, especially for the purpose of data collection, interpreters were made to follow the following approach as means of proper scrutinizing the data collection process:

- To avoid introducing more bias in the data collection process, different land uses were discussed, and a guide created for all classes to help participants in their interpretation.
- In situations where an interpreter encountered difficulty with interpretation of a plot, a screen was projected for discussion by the whole group to reach consensus on the classification for the plot.
- 2.5% of the total sample plots were duplicated and shared amongst interpreters in a form of blind reassessment. This was to ensure a robust QA/QC was conducted to avoid any form of bias.

To assess the level of interpreter agreement, 598 sample plots were blindly re-assessed by a different interpreter. This corresponds to approximately 8% of the entire sample. The exercise resulted in an interpreter agreement of 79%, which in comparison to interpreter agreement assessments in other countries is a fair level of agreement.

To improve the quality of the plot interpretation all sample plots that were labeled by the interpreter as "low confidence" were re-assessed and all forest or deforestation sample plots assessed in June 2019 are re-assessed since at that time the interpreters did not have access to Planet data.

10.2 QA/QC of the emissions factors from the FPP project

Fifteen randomly selected plots from the Moist Evergreen, Moist-Semideciduous South-Eastern and North-Western zones were revisited as quality control plots, and twelve out of these plots were revisited in field for quality control, corresponding to 3.3 per cent of the total 358 planned plots and 4.1 per cent of the plots with measured data.

10.3 QA/QC data analysis

Several rounds of quality control took place by the GFC team, supported by the experts from CfRN. This QC helped with checking the correct implementation of the IPCC equations, consistency between the values included in the REDD+ foundational platform and the analysis of the results. All issues encountered were addressed and mistakes corrected when identified.

11. PROPOSED IMPROVEMENTS

In line with the stepwise approach to developing a country's FREL/FRL, Ghana submits this current FREL/FRL recognizing that some aspects in the construction of future FREL/FRL will require further improvements within the near and far future. It is expected that, in future submissions, Ghana will address the following identified improvements.

Data from Collect Earth

Ghana intends to collect more sample plots especially over areas outside the area covered by Ghana Cocoa Forest Redd+ Programme. Currently most of the sample plots fall in closed forests and the next round of data collection would mostly be in open forests.

Uncertainty analysis of the AD

Once data collection has been completed, uncertainty analysis of the activity data should take place, which will serve as an input for the uncertainty analysis of the GHG inventory and updated FRELs.

Emission Factors

As part of stepwise improvement, it is envisaged that Ghana conducts a revision of the 2012 data from the Forest Preservation Programme (FPP), most of which have been used to generate the EF's for this FREL/FRL submission. It is believed that the data will be enhanced when Ghana is availed to better and more improved methodology and datasets.

Broadening the scope of the FREL/FRL

Ghana is at the verge of issuing FLEGT license. This is expected to improve sustainable forest management in the country. In this regard, rigorous data is expected to be available for this REDD+ activity and its inclusion in future submission(s).

Combination of Maps and Sampling Based Approach

Ghana is currently working on improving the accuracies of the country's land cover maps. Once that is satisfactorily done, change maps would serve as the stratifier for the sampling.

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13. ANNEXES

13.1 Annex I. Soil Organic Carbon – SOC

As already indicated, in this submission the Soil Organic Carbon – SOC was not included in the FREL construction due to the non-significance of the changes in carbon stock due to conversion of Forest Land to Cropland and to Grassland, as demonstrated in sequence. Organic soils are rare in Ghana and hence have not been addressed here

Reference SOC (SOC_{REF}) for mineral soils

To estimate the annual change in organic carbon stocks in mineral soils from land conversion to a new land use, equation 2.25 in the 2006 IPCC GLs was used and required an estimate of the reference carbon stock. The guidelines provide default reference soil organic carbon stocks for mineral soils (under native vegetation) for different climate regions. Ghana applied the updated default SOC_{REF} values in Table 2.3 in the 2019 Refinement, volume 2, page 2.35. The data in this table are provided for Tropical Dry, Tropical Moist and Tropical Wet climate zones.

To estimate SOC_{REF}, two steps were necessary: (1) to estimate the percentage share of Dry, Moist and Wet climate zones in the country; and (2) to estimate the percentage share of the main soil types in the country in the soil categories provided by the IPCC (High Activity Clay soils (HAC); Low Activity Clay soils (LAC); Sandy soils; Spodic soils; Volcanic soils; and Wetland soils. These were necessary to generate a weighted average estimate for SOC_{REF}. The estimates for (1) resulted from Figure 24 (a), which indicates the percent contribution of distinct climate zones in Ghana. These percentages were used to estimate the share of *Tropical Dry climate zone* (33% from Northern Savannah zone and 9% from the Coastal Savannah zone); *Tropical Moist climate zone* (22% from the transitional zone and 15% from the deciduous forest zone); and finally, the *Tropical Wet climate zone* (15% from the high forest zone). Hence, the Tropical Dry, Moist and Wet climate zones in Ghana represent approximately 42 per cent, 43 per cent and 15 per cent in Ghana. Additionally, it is necessary to identify the main soil types in the country mentioned in (2). For this, the results in *Deng et al.* (2016) were used.

Figure 24 (b) shows the soil units of Ghana, with a large prominence of Ferric Luvisols (High Activity Clay (HAC) soil), covering approximately 50 per cent of Ghana's territory, followed by Orthic Acrisols (Low Activity Clay (LAC) soil), contributing to 25 per cent, Plinthic Luvisoils (HAC soil) with 10 percent, Dystric Nitosols (LAC soil) with 5 per cent, Lithosols with 5 percent (LAC soi), Xhantic Ferrasols with 5 per cent (LAC soil). In summary, although these percentages are subjectively estimated by visual analysis, they can be used as a proxy – 60 per cent of the soil is considered HAC soils and 40 per cent LAC soils.

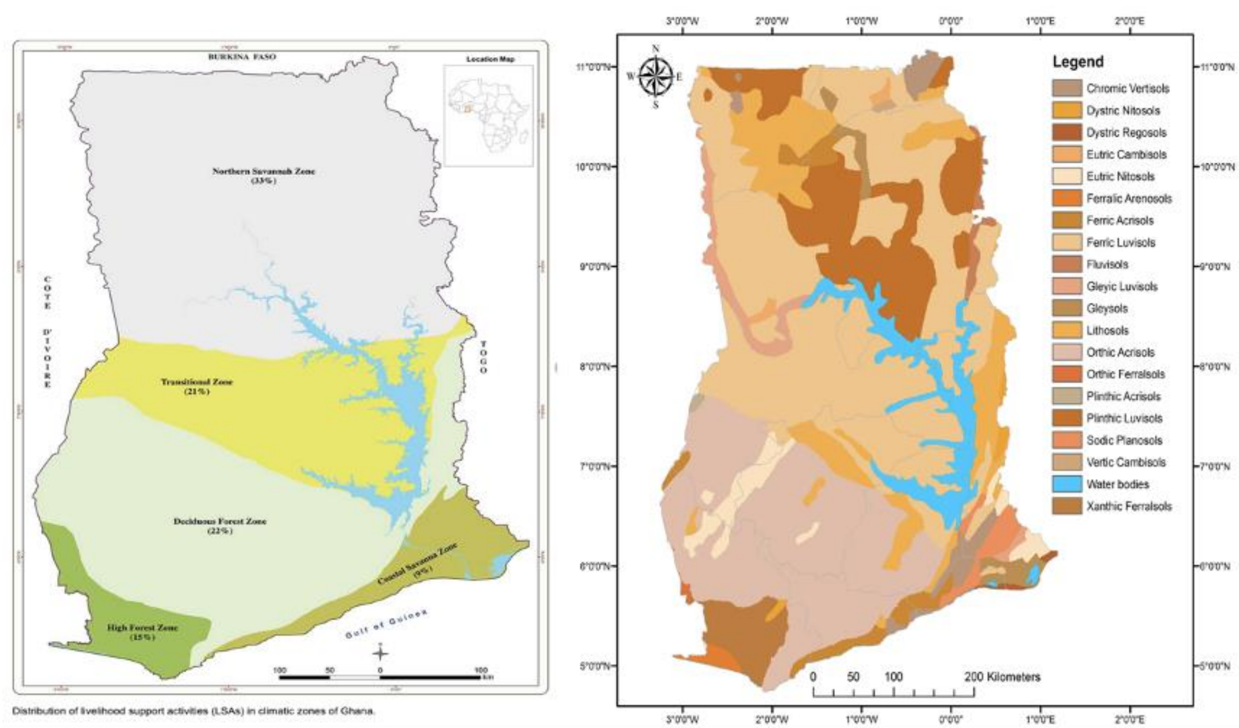

Figure 23 (a) Main climate zones in Ghana; (b) Soil units of Ghana (FAO, ISRIC)

With this information the SOC_{REF} was estimated, as shown in Table 62

Table 61. Estimation of SOC_{REF} for Ghana

	% COVER	HAC tC/ha	LAC tC/ha	HAC (60%)	LAC (40%)	TOTAL HAC+LAC tC/ha	Total x % cover tC/ha
Tropical Dry	42	21	19	15.96	7.6	23.56	23.56*0.42=9.90
Tropical Moist	43	40	38	24.0	15.2	39.2	39.2*0.43=16.86
Tropical Wet	15	60	52	36.0	20.8	56.8	56.8*0.15=8.52
SOC_{ref}							**35.27**

In parallel, some published results in the literature were also assessed for the sake of comparison and are presented in Table 63.

Table 62.. Sone Soil Organic Carbon estimates in the country-specific literature.

	Some literature assessed
Savannah Woodland	30.02 ± 13.20 tC ha^{-1} - Bessah *et al*. (2014)
Natural forests	26.05 tC ha^{-1} - Mahamahadu (2015); 27.21 tC ha^{-1} – Adu-Bredu *et al*. (2010) for Savannah zone; 24.54 tC ha^{-1} - Adu-Bredu *et al*. (2010) for Dry Semideciduous Forest; 72.74 tC ha^{-1} - Adu-Bredu *et al*. (2010) for Moist Evergreen, 36.35 tC ha^{-1} - Mahamahadu (2015)
Transition zone	21.2 tC ha^{-1} - Tan *et al.* (2008)
Moist semi-deciduous	67.4 ± 1.1 tC ha^{-1} - Dawoe (2009 – 0-60 cm); 43.38 ± 2.6 tC ha^{-1} (0-20 cm) – Agboadoh (2011)
Semi-deciduous	43.5 tC ha^{-1} – Owusu *et al*. (2020)

Note: the estimates in Adu-Bredu *et al*. (2010) are provided for two soil depths: (0 – 20 cm) and (20 – 40 cm). The estimates in the table provide the value for (0 – 30 cm), assuming half of the value estimated at (20 – 40 cm).

Changes in SOC carbon stock in mineral soils from conversion of Forest Land to Cropland

Box 2.1 in the Refinement provides Formulation B (Approaches 2 and 3 for Activity Data Collection) which was applied in this submission. The stock change factors (land use, management regime and input of organic matter) have also been updated in Table 5.5, page 5.27 of the 2019 Refinement. The equation below reflects the alternative formulation in Box 2.1 of the 2019 Refinement.

$$\Delta C_{Mineral} = \frac{\sum_{c,s,p}\left[\begin{Bmatrix}\left(SOC_{REF_{c,s,p}} \bullet F_{LU_{c,s,p}} \bullet F_{MG_{c,s,p}} \bullet F_{I_{c,s,p}}\right)_0 - \\ \left(SOC_{REF_{c,s,p}} \bullet F_{LU_{c,s,p}} \bullet F_{MG_{c,s,p}} \bullet F_{I_{c,s,p}}\right)_{(0-T)}\end{Bmatrix} \bullet A_{c,s,p}\right]}{D}$$

Where:

$DC_{Mineral}$ = annual change in carbon stocks in mineral soils, t C yr^{-1}

SOC_0 = soil organic carbon stock in the last year of an inventory time period, t C

$SOC_{(0-T)}$ = soil organic carbon stock at the beginning of the inventory time period, t C

T = number of years over a single inventory time period, yr

D = time dependence of stock change factors which is the default time period for transition between equilibrium SOC values, yr

c represents the climate zone, *s* the soil types, *p* is a parcel of land representing an individual unit of area over which the inventory calculations are performed

SOC_{REF} = the reference carbon stock, t C ha^{-1}

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

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

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

A = land area of stratum being estimated, ha

The values selected from the updated Table 5.5 for the stock change factors were F_{LU} = 1 (long-term perennial tree crops); F_{MG} = 1 (full tillage, substantial soil disturbance with frequent tillage operations); and F_{I} = 0.95 for Tropical Dry and 0.92 for Tropical Moist and Wet regimes (Low input). Assuming the share of Tropical Dry, Tropical Moist and Tropical Wet climate zones estimated for the country (43 per cent, 42 per cent and 15 per cent, respectively), then the product of F_{LU} x F_{MG} x F_{I} is 0.94 (0.42*0.95 + 0.43*0.92 + 0.15*0.92).

Since SOC_{REF} = 35.27 tC ha^{-1}, the change in carbon stock from conversion of Forest Land to Cropland is (35.27 * 0.94 = 33.15 tC ha^{-1}). The annual loss of carbon stock in SOC in mineral soil is then 2.11 tC ha^{-1} yr^{-1}/20 years = 0.11 tC ha^{-1} yr^{-1}. This is the value estimated using the IPCC methodology.

Just for comparison sake, two other studies are also mentioned here. Bessah (2014) carried out an assessment of soil organic carbon stocks under various land use/land cover types in Kintampo North Municipal, Ghana. For cropland, an estimate for SOC of 25.73 (standard deviation of 8.95, n=6) is provided. If this estimate is used for Cropland, then the annual loss of carbon stock in SOC in mineral soil is then 9.54 tC ha^{-1} yr^{-1}/20 years = 0.48 tC ha^{-1} yr^{-1}. This study was selected since the Savannah ecological and climate zones have the highest share in the Ghanaian territory.

The mean SOC stock of 25.73 tC ha^{-1} for cropland from Bessah (2014) is comparable with the estimate from Adu-Bredu *et al*. (2010) for SOC stocks in Bawku in the Guinea Savanna zone of Ghana. For cultivated land use in the Savannah, the SOC estimate is 26.74 tC ha^{-1} (21.45 tC ha^{-1} at 0 – 20 cm and 5.29 tC ha^{-1} at 20 - 30 cm (assuming half of the estimate at depth 20-40 cm, of 10.57 tC ha^{-1}). Adu-Bredu *et al*. (2010) also provides an estimate of SOC for natural forest in the Savannah zone, equal to 27.21 tC ha^{-1} (22.28 tC ha^{-1} at 0 – 20 cm and 4.93 tC ha^{-1} at 20 - 30 cm (assuming half of the estimated SOC at depth 20-40 cm, of 9.86 tC ha^{-1}). Hence, in the Savannah zone, the largest ecological zone in Ghana, the change in SOC from natural forest to cultivated land is 0.47 tC ha^{-1} which, distributed in 20 years, provides an annual change in SOC of 0.0235 tC ha^{-1} yr^{-1}. All these estimates indicate that the SOC change from conversion of Forest Land to Cropland is not significant.

Changes in SOC carbon stock in in mineral soils from conversion of Forest Land to Grassland

The approach used to estimate the change in carbon stock in SOC in mineral soils from conversion of Forest Land to Grassland is the same as that used for Forest Land converted to Cropland. The stock change factors (land use, management regime and input of organic matter) used in this submission are those updated in the IPCC 2019 Refinement in Table 6.2, page 6.6. The values selected from the updated Table 6.2 for the stock change factors were F_{LU} = 1 (long-term perennial tree crops); F_{MG} = 1 (full tillage, substantial soil disturbance with frequent tillage operations); and F_I = 1 for Tropical Dry and for Tropical Moist and Wet regimes (Low input). With all factors equal to 1, there is no change in the SOC due to the conversion of Forest Land to Grassland.

For information sake, some results in the literature (e.g., Deng et al. (2016) and Fujisaki *et al*., 2015)) indicate that, on average, the conversion of forest to grassland either increases the soil organic carbon stock over time, or no significant changes occur. See summary of the study by Deng et al. (2015) (see Box 1).

The paper reviews the literature on the effects of land-use conversions on soil C stocks, based on a synthesis of 103 recent publications, including 160 sites in 29 countries, with the aims of determining the factors responsible for soil C sequestration and quantifying changes in soil C stocks from seven land use conversions. The results show that as an overall average across all land use change examined, land use conversions have significantly reduced soil C stocks change examined, land-use conversion shave significantly reduced soil C stocks (0.39 Mg ha⁻1 yr^{-1}). **Soil C stocks significantly increased after conversions from farmland to grassland** (0.30 Mg ha⁻1 yr^{-1}) and forest to grassland (0.68 Mg ha⁻1 yr^{-1}), but significantly declined after conversion from grassland to farmland (0.89 Mg ha⁻1 yr^{-1}), forest to farmland (1.74 Mg ha⁻1 yr^{-1}), and forest to forest (0.63 Mg ha⁻1 yr^{-1}). **And after conversion from** farmland to forest and **grassland to forest, soil C stocks did not change significantly.** Fig.24 below, showing an average increase in soil C sequestration (tC ha^{-1}) from forest to grassland and farmland to grassland.

Box 1 . Deng, L.; Zhu, G-yu; Tang, Z-sheng; Shangguan, Z-ping (2016) Global patterns of the effects of land-use changes on soil carbon. Global Ecology and Conservation 5:127–138.

GRAPHICAL ABSTRACT

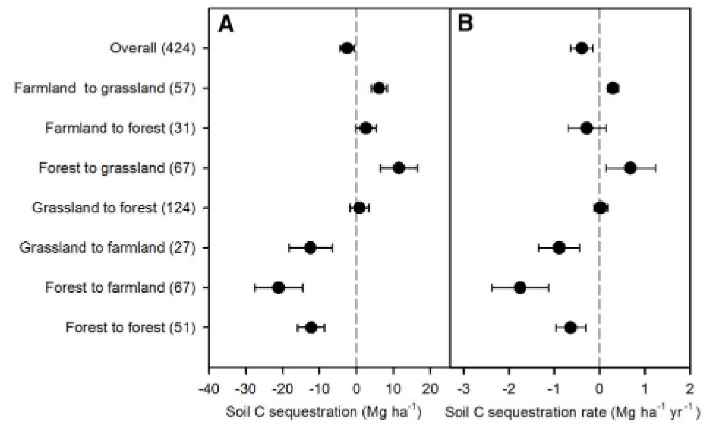

Figure 24 average increase in soil C sequestration (tC ha^{-1}) from forest to grassland and farmland to grassland

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Manual 5-2: Biomass Field Measurement Techniques (Section 3)

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