GHANA'S NATIONAL FOREST REFERENCE LEVEL

2001 - 2015

Forestry Commission

GhREDD+

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LIST OF ABBREVIATIONS AND ACRONYMS

AGB	Above-Ground Biomass
AD	Activity Data
AFOLU	Agriculture, Forestry and Other Land Use
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	Forestry Commission, Ghana
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
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
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
RMSC	Resource Management Support Centre
REDD+	Reducing Emissions from Deforestation; Reducing Emissions from Forest Degradation; Conservation of Forest Carbon Stocks; Sustainable Management of Forests; and Enhancement of Forest Carbon Stocks
S	Settlements
SAR	IPCC's Second Assessment Report
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 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 methodologies 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 been updated. 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 equivalent per year. The submission in 2017 indicated that the country was a net source of CO_2.

The main difference between the submission in 2017 and the current one relates to the approach for activity data generation. The 2017 FRL included deforestation estimates following a stratified area estimate approach. The land use maps used to estimate the areas and their change were based in three land-use 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, and 4x4km grids) 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. On the other hand, this submission also makes use of degradation estimate based on logging, fuel wood and fire.

REDD+ Activity	Activity data		Emission factor	
	FREL/FRL 2017	FREL/FRL 2021	FREL/FRL 2017	FREL/FRL 2021
Deforestation	Landsat satellite imagery (T3)	Sample points interpreted in Collect Earth	Field data collected by FC (T3), Peer-reviewed published literature: Kongsager et al. (2013) (T2), IPCC defaults i.e. Tier 1 (T1)	Field data collected by FC (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	Wood removals (Logging, fire and fuelwood)	field data for legal logging;T1 assumptions for fire emissions; IPCC defaults for fuelwood	Field data from FC, IPCC defaults (T1)
Enhancement	FC field data	Sample points interpreted in collect earth	Peer-reviewed published literature and IPCC defaults	Peer-reviewed published literature and IPCC defaults

This current submission also uses the reference period 2001-2015 and the construction of the national 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 supplementary materials offer detailed information on historical emissions from all REDD+ activities included, 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 (logging and fire)
Enhancement of C Stocks	Land Converted to Forest Land

The current submission corresponds to an average of 19,659,303 tonnes of carbon dioxide equivalent per year. This assessment indicates that in the last 15 years, about 209,034 ha of forest have been cleared and converted to other land use categories, with an average of 13,065 ha per year. This has resulted in a total forest loss of 2.88% in 15 years, moving from 4,208,373 ha in 2000 to 4,068,905 ha 2015, corresponding to 17% of forest cover with respect to total country area. The main drivers of deforestation were conversion to croplands and grasslands; and for forest degradation were legal and illegal logging, fuelwood extraction and fires.

I. BACKGROUND

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

(a) Establishment of Ghana's historical emissions profile from the forestry sector
(b) The development of the revised 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. Therefore, Ghana intends to achieve the following national and international objectives with the submission of the revised 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 consistent with the Paris Agreement.

Internationally:

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

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 carbon emissions from deforestation and forest degradation. Recognizing the immense benefits of REDD+, Ghana engaged in REDD+ a little over 10 years ago and have achieved remarkable progress including the development of the REDD+ Strategy in 2016. Subsequently in 2017, Ghana submitted a Forest Reference Level which has undergone technical assessment for re-submission to the UNFCCC. The assessment has been occasioned by the availability of a more rigorous methodology, which is reflective of Ghana's landscape.

Ghana has a total land area of 23.9 million ha. In the year 2000, forests are estimated to have covered 4.2 million hectares which has declined to 4.1 million ha with a historical total deforestation of 2.88% (appx 13,000 ha yr-1).

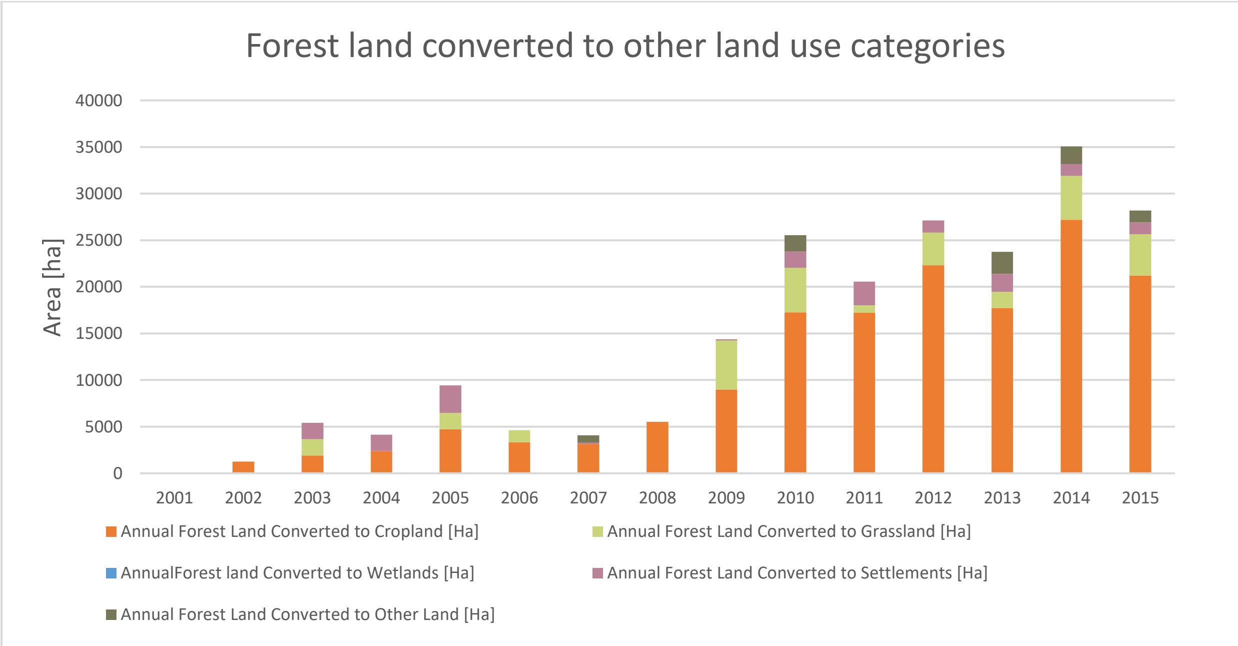
Ghana's total forest area is divided into three main ecological zones; the High Forest zone (HFZ), Transitional Zone (TZ) and the Savannah Zone (SZ). These zones have been delineated based on climatic factors, notably rainfall and temperature. The main ecological zones are subdivided into nine forest strata (as shown in Figure 3.)

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 0.19% annually (13,065 ha) , 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 source 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.

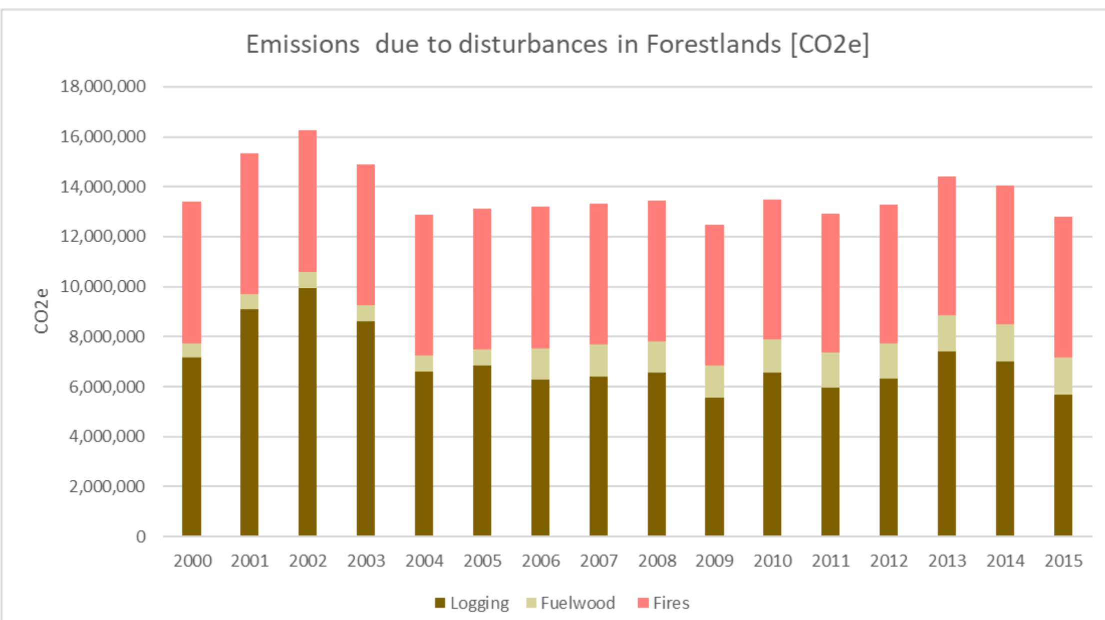
Figure 1. Forest land converted to other land use categories (deforestation) [ha]

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



Source: Collect earth assessment by FC.

Figure 2. Disturbances in Forest land remaining Forest land (Degradation) [CO2e]



Source: Forestry Commission, Ghana

1.3 Application of UNFCCC Modalities to Ghana's Revised FRL

The construction of the 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 FRL by incorporating better data, improved methodologies and, where appropriate, additional pools. The FRL is expressed in units of tons of CO_2 equivalent (CO_2e) per year and should 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 1. UNFCCC modalities relevant to Ghana's national FRL.

Reference to Guidelines	Description	Ghana's Proposal
Decision 12/CP.17 Paragraph 1	Allows for a step-wise approach	Ghana developed a sub-national FRL for the GCFRP[3] 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, Litter, Deadwood and Soil organic carbon have also been included in this submission. 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_2e.
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[4]
Decision 12/CP.17 Annex	The information should be guided by the most recent IPCC guidance and guidelines.	FRLE/FRL estimates were developed using the 2006 IPCC Guidelines and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[5]
Decision 12/CP. 17 II. Paragraph 9	To submit information and rationale on the development of forest	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

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

[3]

[4] 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.

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

	FRLs/FRELs, including details of national circumstances and on how the national circumstances were considered	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).

II. KEY ELEMENTS

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

- **Paragraph 7**. The FREL presented by Ghana is expressed in tons of CO_2 equivalent per year (t CO_2e), to serve as a benchmark for assessing the country's performance in implementing the REDD+ activities.

- **Paragraph 8.** Ghana aims to ensure full consistency in submissions to the UNFCCC (e.g., National GHG inventories, REDD+, national communications, BURs). Thus, most of the information included in the development of this FREL/FRL was the one used in the Ghana NIR. All calculations are explicit to maximize transparency.

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

- **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[6]. Also, extensive descriptions of the methods and data used are provided below to facilitate understanding by the readers and the UNFCCC technical assessment team.

- **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

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[6] https://cfrnorg-my.sharepoint.com/:f:/g/personal/milena_cfrn_org/EnWD7TVwQnRNoVvPiGCc-AQBuJxXVXFnwuCCzIWQG2RscQ?e=FPbqVS

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 National GHG inventory.

III. 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 forest 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.**

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, only emissions from anthropogenic causes are included.

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 boundaries of 15% canopy cover and above. Human disturbances are illegal logging, fire, shifting cultivation, infrastructure, and (livestock) grazing.

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 use categories converted to Forest land 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 broad land-use categories.

Table 2. Depicting associated REDD+ activity, source categories and sub-categories

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 (logging, fuelwood, fire)
Enhancement of C Stocks	Land Converted to Forest Land, Forest Land Remaining Forest Land (Disturbed)

IV. 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-GHG 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, 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 were 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.

V. NATIONAL CIRCUMSTANCES

5.1 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[7]. Nine vegetation zones are identified in Figure 3.

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.

7 Ghana REDD+ Strategy, 2016.

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.

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 savannah, in the forest zone, and in the northern savannah zone.

The coastal savannah 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 savannah 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 savannah gives way to a more open type of grassland that has developed largely as a result of prolonged human interference.

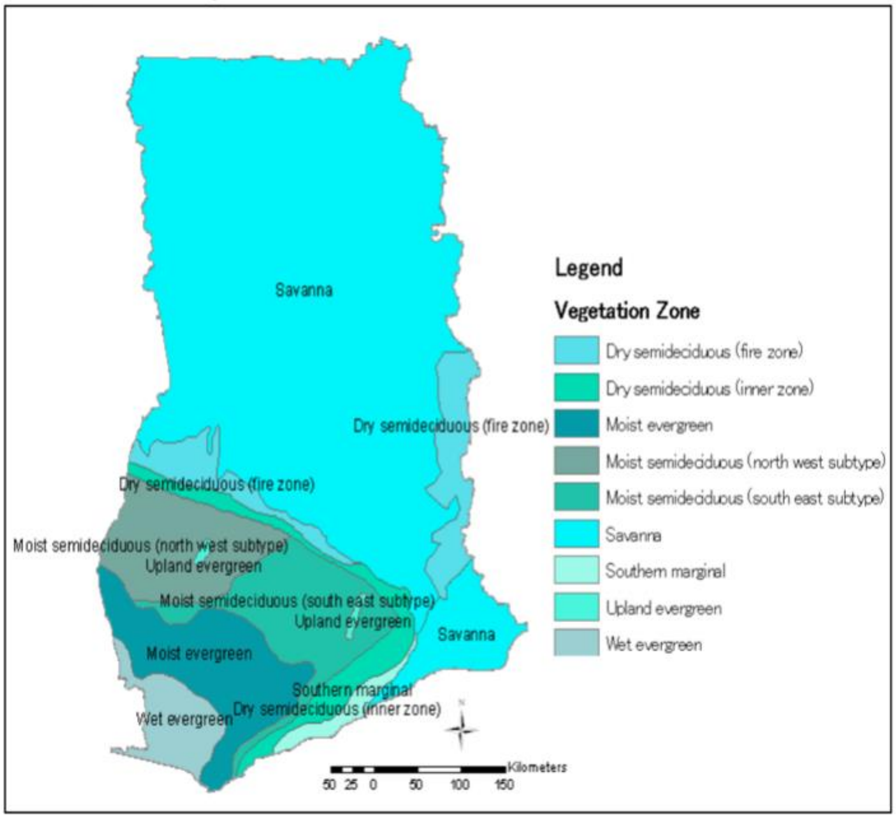


Figure 3. Ghana's distribution of Vegetation Zones[8] .

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.

5.2 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 3). The country has had an established history of laws governing the forest sector since 1906. There is

[8] Report on Mapping of Forest Cover and Carbon Stock in Ghana, Figure 1.1 (Project Areas and their Extent), PASCO CORPORATION, Japan, in collaboration with FC-RMSC, CSIR-FORIG and CSIR-SRI, Ghana. April, 2013.

currently a range of policy and regulations that impact the sector, and several government bodies that oversee its operation.

Table 3. 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	Forest Law Enforcement, Governance and Trade (FLEGT) Initiative (as part of the Voluntary Partnership Agreement (VPA)), and the projects under Ghana's FIP all

(FLEGT)	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 reservoirs 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 Forest Plantation Strategy (2016-2040)	The GFPS identifies challenges to past efforts and consequently outline the strategic direction, actions and resources required to promote the development of productive and sustainable planted forests. It indicates the technical and financial resources required and performance indicators necessary to track progress over the period (2016 to 2040).
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.

5.3 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 land remaining forest land, and forest land converted 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)[9], provided in this submission. All land in the country is considered to be managed land.

5.4 Carbon pools

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

5.5 Greenhouse gases

The national FREL/FRL includes emissions of **carbon dioxide (CO_2),** and **methane (CH_4)** and **nitrous oxide (N_2O)** from biomass burning in Forest Land. Emissions in carbon dioxide equivalents (CO_2e) are reported using the **100-year global warming potentials** (GWPs) contained in **IPCC's Second Assessment Report (SAR)**.

5.6 Scale

The scale of the FREL/FRL is National. The total land area is 239,154 square kilometers (km^2) (23,915,421 ha). The country is divided into 16 regions with 9 ecological zones (Figure 3). A stratified systematic sampling grid of 18,009 plots, of 0.5ha and 1ha in size, located across the entire country was used to allow a national coverage of Ghana's landscape.

5.7 Reference Period

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

5.8 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.

The average FREL/FRL is set as a continuation of the historical average, which can have different implications 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.

[9] The REDD+ Foundational Platform is similar to the IPCC working sheets, but is adapted to capture specific country needs and circumstances. https://cfrnorg-my.sharepoint.com/:f:/g/personal/milena_cfrn_org/EnWD7TVwQnRNoVvPiGCc-AQBuJxXVXFnwuCCzIWQG2RscQ?e=FPbqVS

The continuation of historical trend FREL/FRL requires assessment of the historical data for identification of a statistical trend. Countries with increasing emissions will project an increasing trend for the FREL/FRL, while countries with decreasing historical emissions will project a decreasing trend for FREL/FRL, making the cuts in emissions for both scenarios more affordable. The application of an adjustment for national (subnational) circumstances to the FREL/FRL requires more detailed analysis and justification regarding the expected changes in the future from specific circumstances 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 4. The FREL/FRL is to be applied as a benchmark for net emission reductions in each year of the period 2016 to 2019. Figure 4 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).

5.9 Period of application of the FREL/FRL

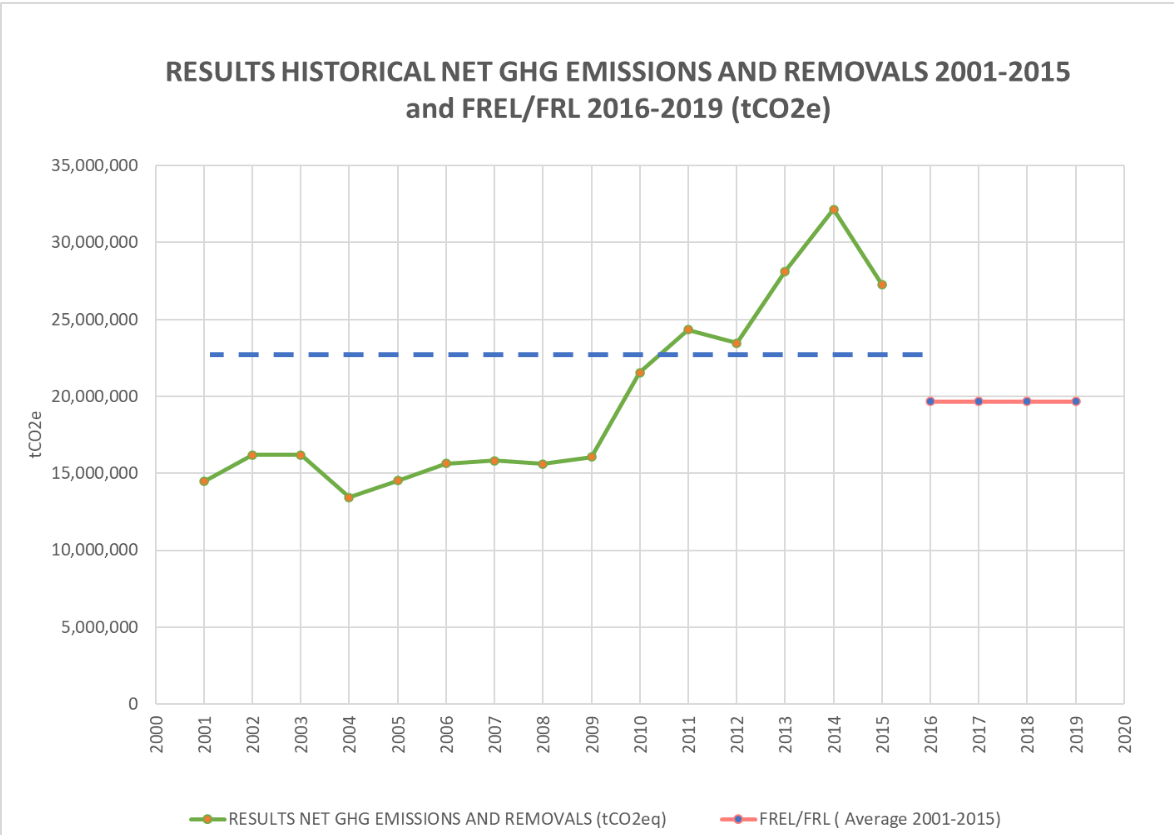
The FREL/FRL will be applied for years 2016, 2017, 2018 and 2019.

Table 4. Calculation of the FREL/FRL (net emissions) in tCO_2e

	Year	tCO2e
Historical NET Forest related GHG emissions and removals [CO2, CH4, N2O]	2001	14,474,487
	2002	16,207,479
	2003	16,196,706
	2004	13,439,751
	2005	14,518,491
	2006	15,634,428
	2007	15,820,043
	2008	15,616,401
	2009	16,055,107
	2010	21,563,912
	2011	24,339,298
	2012	23,461,630
	2013	28,131,356
	2014	32,163,953
	2015	27,266,496

FREL/FRL [CO2, CH4, N2O]	2016	19,659,303
	2017	19,659,303
	2018	19,659,303
	2019	19,659,303

Figure 4. Historical GHG Emissions and Removals, and FREL/FRL of Ghana



VI. 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.

6.1 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	Forestry Commission, Ghana (FC)
Allocation of tasks	FC
Technical training	Food and Agriculture Organization(FAO), Coalition for Rainforest Nations(CfRN)
Data collection	FAO, FC
QC/QA procedures	FAO, FC, CfRN
Data analysis	FC, CfRN
Compilation of the FREL	FC
QC/QA procedures	CfRN

6.2 Means of data acquisition and management

6.2.1 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 both the 0.5ha and 1ha sample plot, deforestation required that less than 15% of the forest canopy remained after 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 a 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

6.2.2 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 template and protocols; and (f) all reports and documentation.

VII. 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 with the activity data and emission factors used in the construction of the FREL/FRL, for each land-use category.

Table 7. 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	T1,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

7.1 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 ecological 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 on data Industrial round wood supply and fuelwood production biomass harvesting. The extraction of biomass has a significant impact on forest land carbon stocks and represents the key dataset for assessing the variation of carbon stocks in forestland remaining forest land. The Resource Management and Support Centre of the Forestry Commission, and the Energy Commission were the primary sources of data on industrial round wood and fuelwood harvesting. The industrial round wood data were segregated into "planned logging" and "unplanned logging". The planned logging refers to permitted systematic and supervised extraction of timber. Unplanned logging is unsupervised removal of timber and unaccounted for in official records as cover loss instead of volume loss, as the tool does not provide that estimation. Data on fire was based on assumptions of portions of forest remaining forest that is susceptible to burning according to ecological zones.

7.1.1 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 suit 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.

7.1.2 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: 4x4 systematic grid for national coverage with 1ha-plots (refer to Figure 5), 4x4 km grid with 0.5 ha-plots over the area covered by the Ghana Cocoa Forest REDD+ Program (GCFRP) and off reserve areas (refer to Figure 6), 2x2 km grid with 0.5 ha-plots in the High Forest Zone and 1x1 km grid in a rare upland forest reserve (refer to Figure 6). 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.

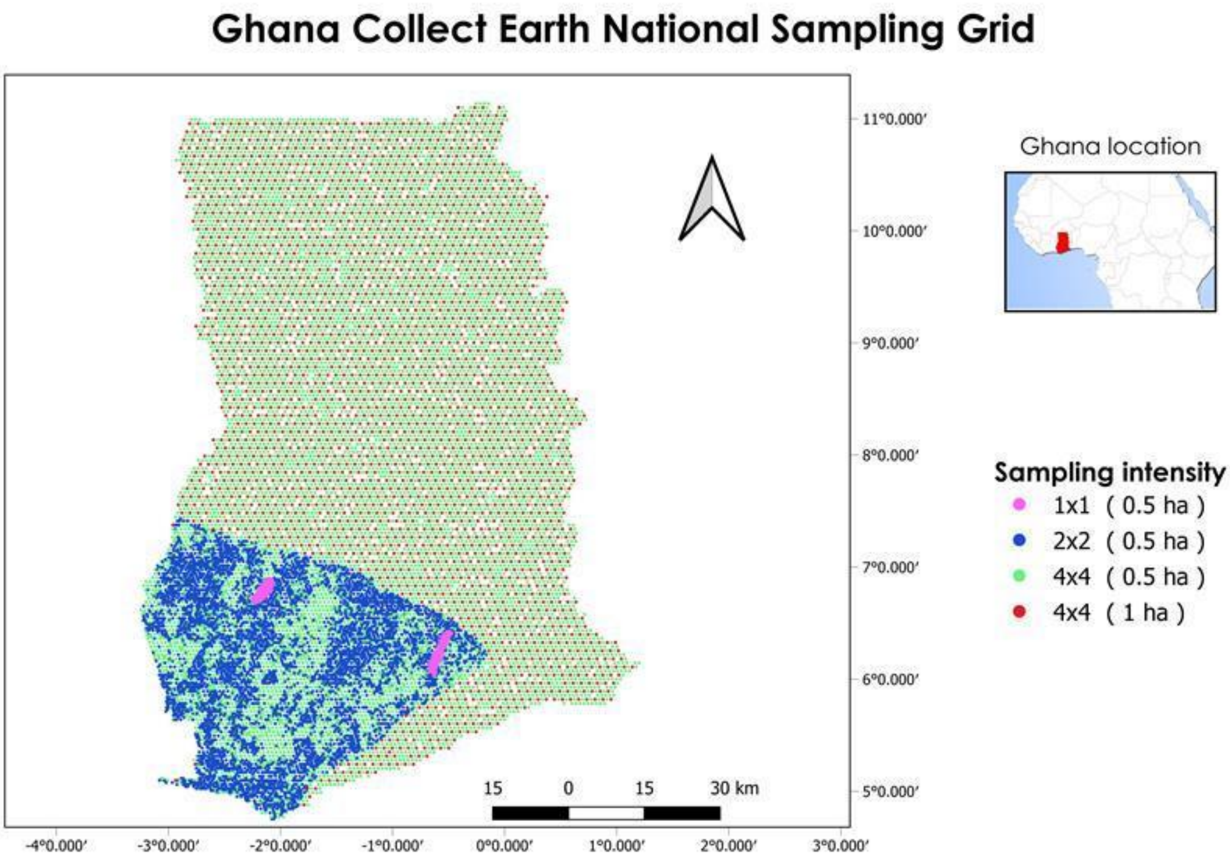
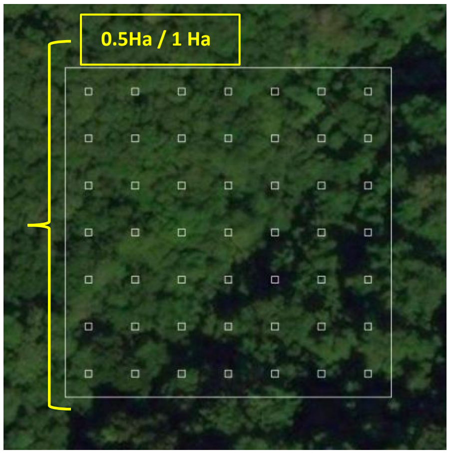


Figure 5. Ghana Collect Earth National Sampling Grid

Figure 6. 4 x 4 intensification in GCRFP (left picture) and 2 x 2 intensification in GCFRP forest and 1 x 1 intensification in upland evergreen (right picture)

Plot Size: 0.5 Ha / 1 Ha

Example distance among plots: 4 Km by 4 Km



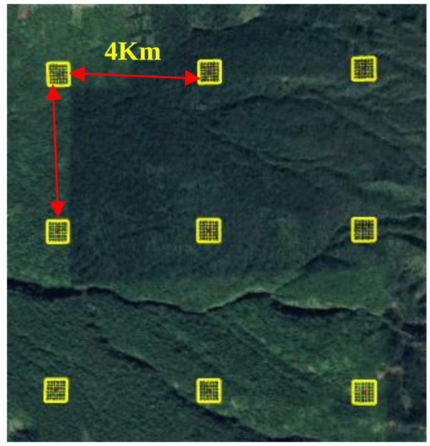


Figure 7. Plot size and distance among plots in Collect Earth

Sampling Intensity

The reason why sampling was intensified in the major forest areas of the country is because ***sampling*** means that a limited sample of plots is used to *infer* the total area of the country based on the *proportion* of plots in the sample under each specific category. Hence, the area a_r (in ha) each plot represents is:

$$a_r = A_T/n$$

where A_T is total country area (in ha) and n is the number of sampling plots.

This representative area a_r does not depend on the plot size, which can even be dimensionless. The deforestation area (D) can then be calculated as follows:

$$D = n_d * a_r$$

Therefore, if the sample increases, the estimate will stabilize and the estimates of area will become closer and closer to each other when sampling intensity increases (Figure 8):

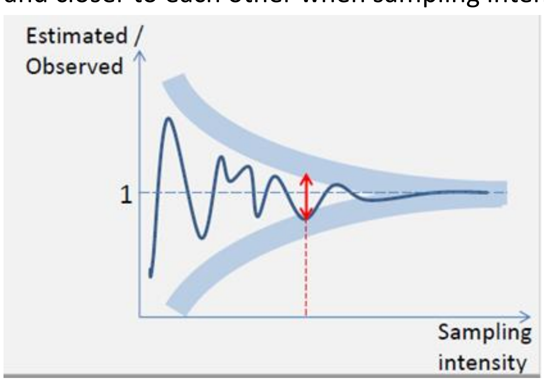


Figure 8 Sampling intensity

Plot Size

Another aspect to consider when using the sampling method is the sampling plot size. When comparing how deforestation is identified using plots of different sizes, deforestation resulted to be different. .

Ghana in the first Collect Earth assessment (10,446 plots) used plots of 0.5ha. However, the current definition for Closed Forest is =>60% canopy, 1 ha and minimum height of 5m; for Open Forest, is < 59%-15% canopy cover, 1 ha and minimum height of 5m. Therefore, the sampling plot size was not fully consistent with this forest definition. During a second assessment, Ghana wanted to increase the sampling intensity in the strata 8 x 8 to have a better representation of the land-use dynamics in that stratum; thus, sampling intensity increased from 8 x 8 to 4 x 4, merging with previous plots already assessed. At the same time, Ghana wanted to take the opportunity to start using plots with a size that is consistent with their forest definition. Thus, the new plots (7,563) were of 1ha.

Ghana experts already identified the impact of a 0.5 ha versus 1 ha plot on the assessment of deforestation and acknowledge the fact that smaller plots might detect more deforestation compared to the 1ha plots; therefore, the new plots might be underestimating deforestation rates. However, this stratum corresponds to the northern part of the country, which is mostly covered by croplands and grasslands, and there is only a small proportion of forest, more specifically Savanna forest.

7.1.3 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 (Figure 9). The diagram below provides an overview of the key steps:

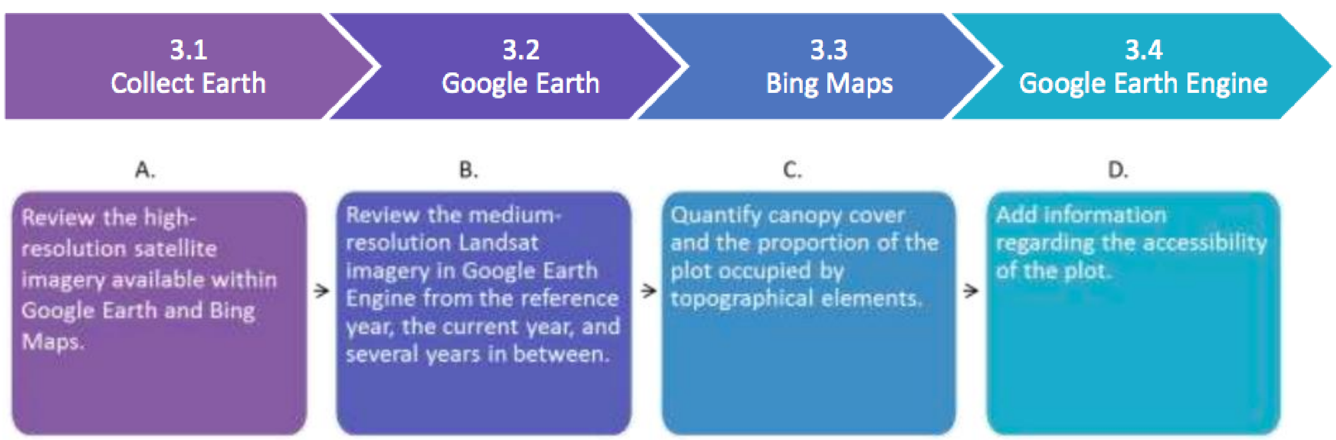
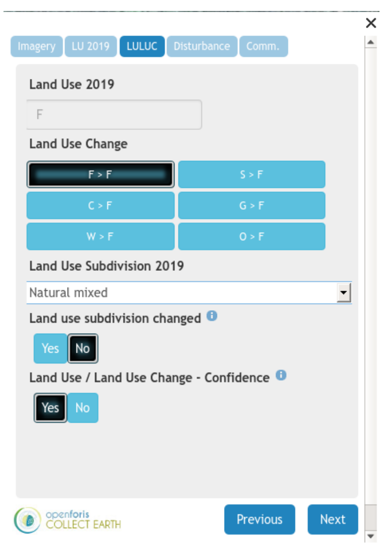


Figure 9 Key steps for image interpretation

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.



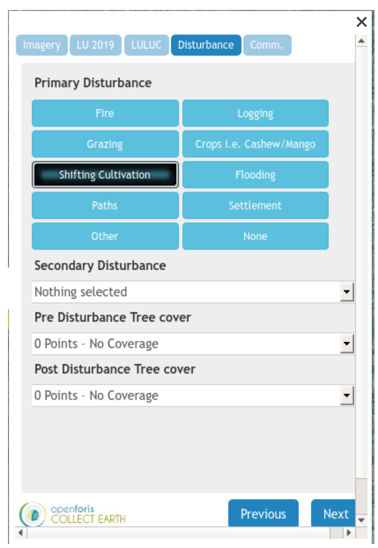


Figure 10 Response Design

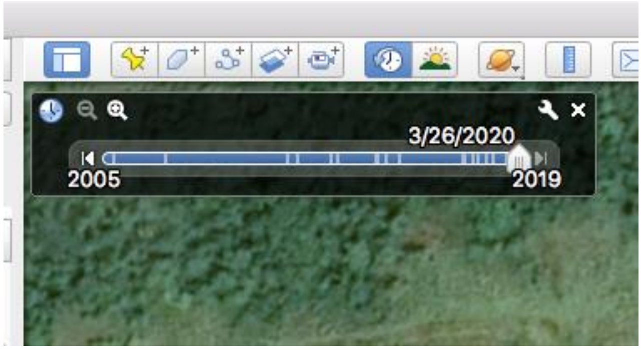


Figure 11. Historical Imagery

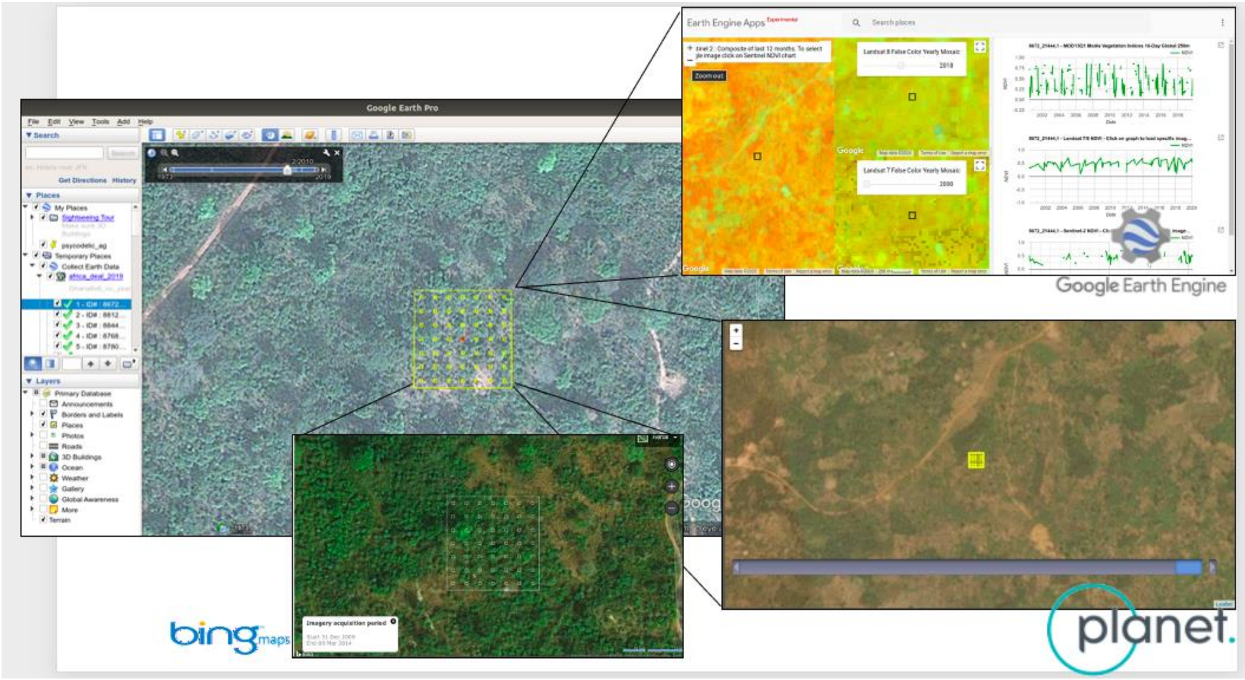


Figure 12. Example of Collect Earth integrated with Bing Maps, Planet & Google Earth Engine

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 and 1 ha undergo visual analysis through a visualization system (Google Earth) that focuses 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 Figures 13 - 16 below:

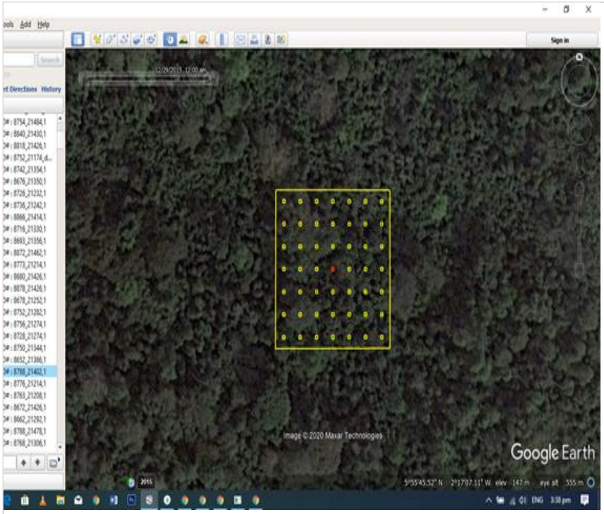


Figure 13 Google Earth Image in 2015

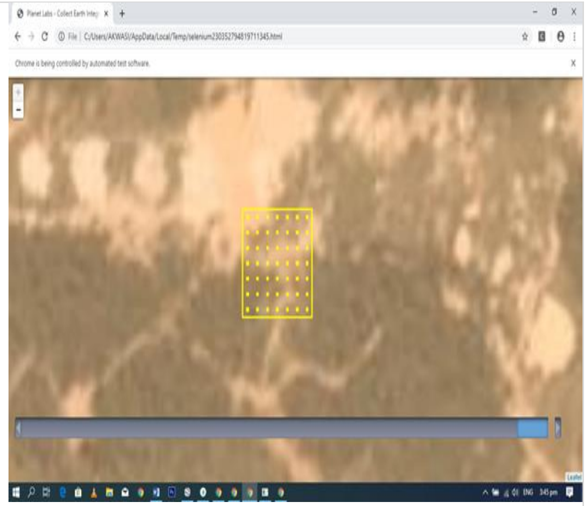


Figure 14 Planet imagery in 2019

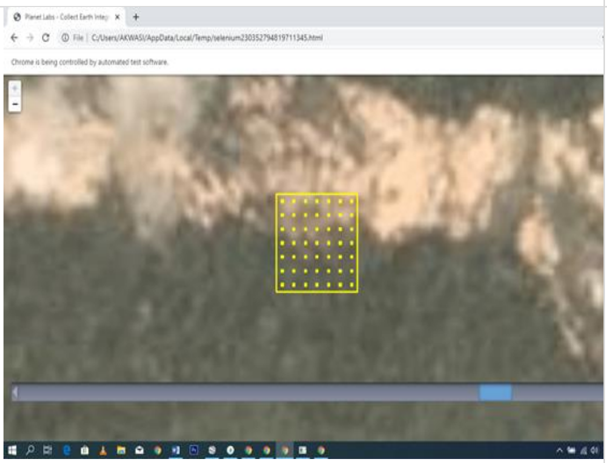


Figure 15. Changes occurred in 2017 observed on Planet imagery

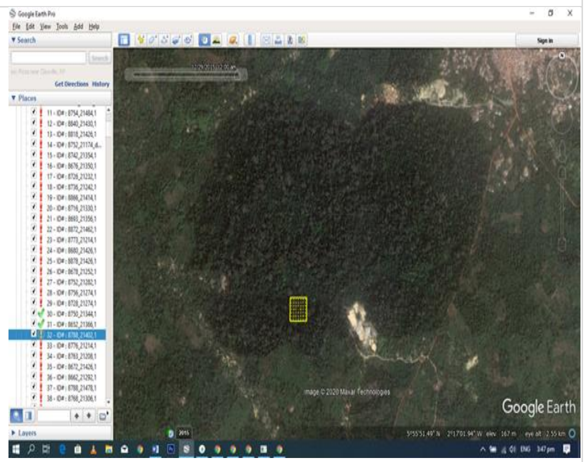


Figure 16 Google Earth image

7.1.4 The **response design**

The response design refers to the rules applied when interpreting a sample plot, i.e. the labeling 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 a 20% 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 broad 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 17).

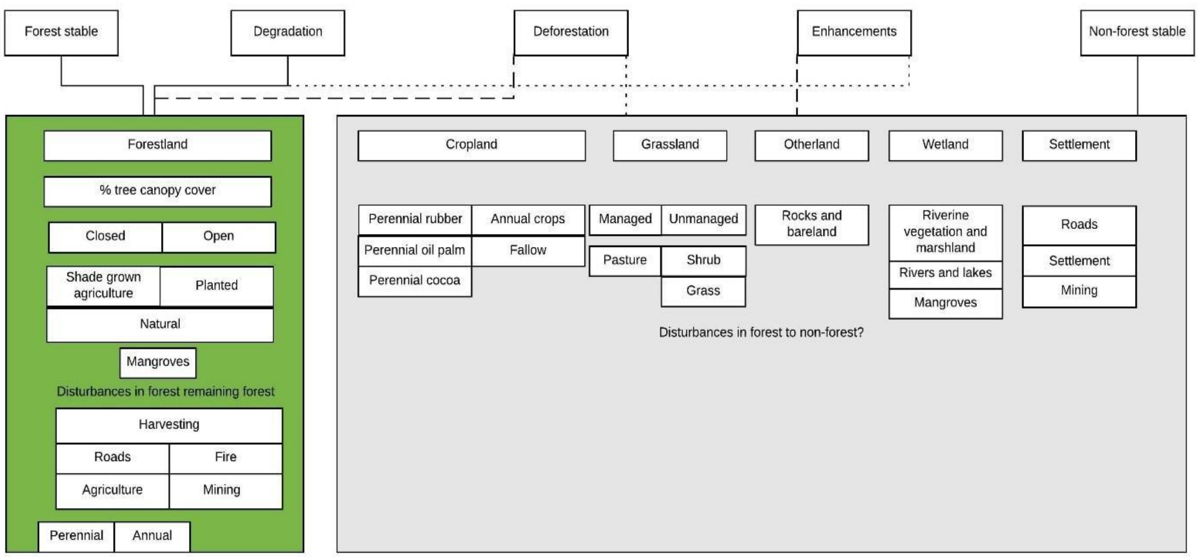


Figure 17. Collect Earth survey structure by IPCC Land Use Categories

7.1.5 Land use classification

Table 8 and figure 18 provide 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 8 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 FC

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)[10]. 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

10 Forest Preservation Programme.

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 a 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.
- **Moist Evergreen** - This is a forest that remains green throughout the year and does not shed leaves. Tree upper canopy trees grow up to 43m high. This stratum is very rich in species diversity and annual rainfall ranges from 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 a 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 a 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**.**
- **Dry Semideciduous** - It has a wide range of annual rainfall (1000 -1500mm), it is heavily degraded because of frequent wildfires. Large portions 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.

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, watermelon, etc**.**
- **Perennial Crop -** these are crops that remain on the ground for more than two years. Examples 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.

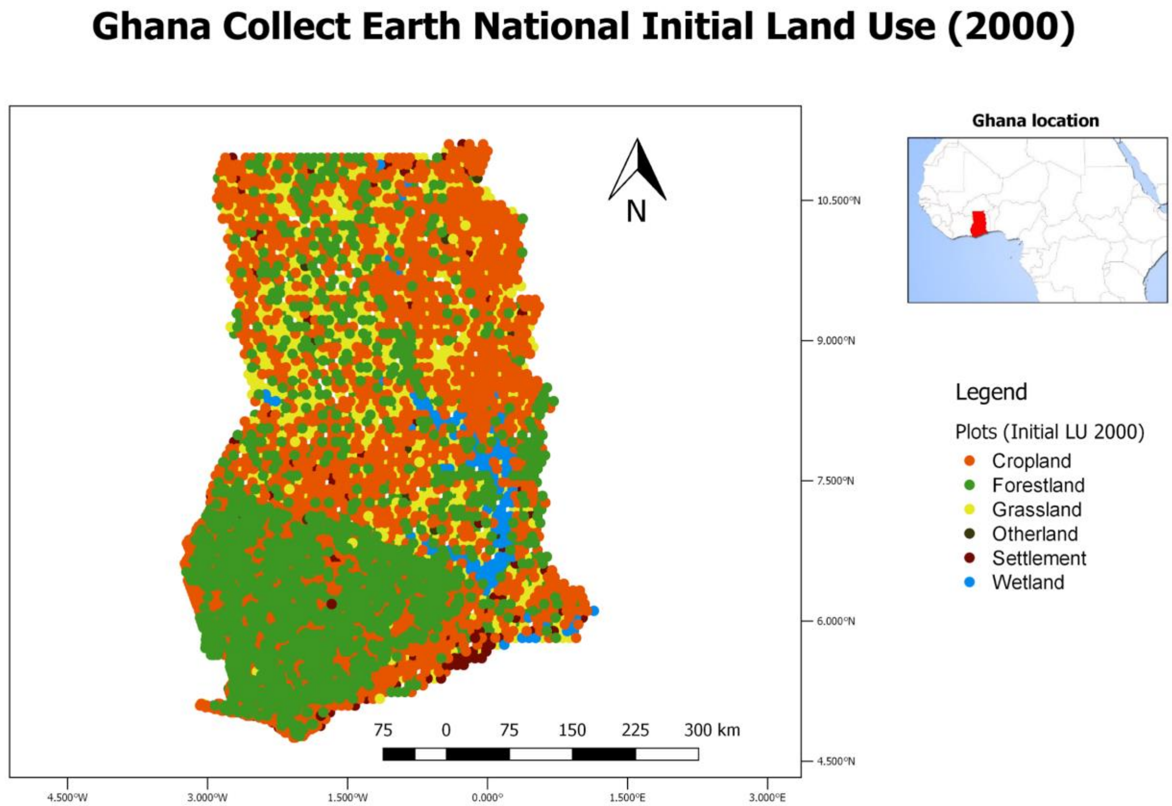


Figure 18 Ghana initial land uses by IPCC categories

7.2 National Forest Inventory

The Report on Mapping of Forest Cover and Carbon Stock in Ghana[11] (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) technology (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.

[11] 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.

7.2.1 The FPP Project – sampling design

The project involved three levels of analysis each carried out in three different areas, as indicated in figure 19. 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".

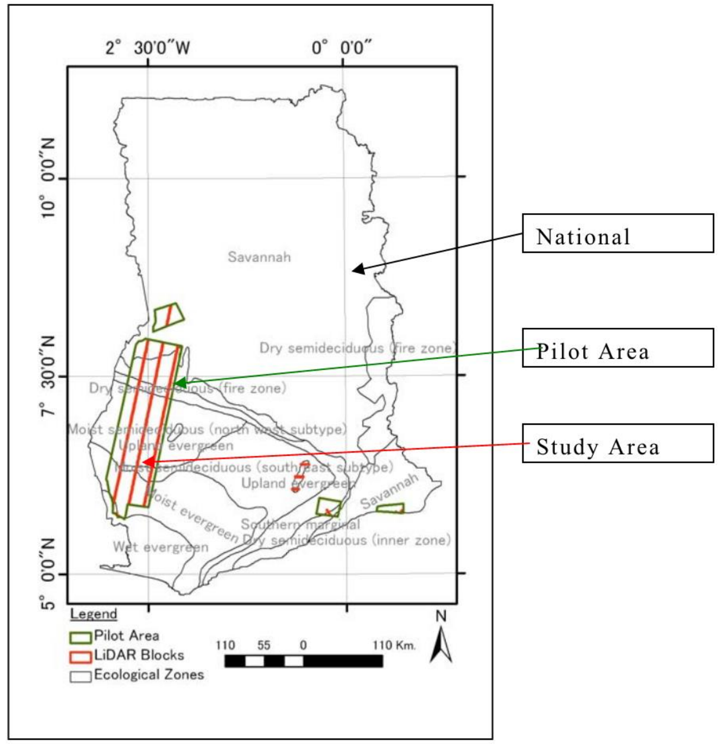


Figure 19 FPP Project Sampling Design

The project had defined a list of expected results, some of which are of direct interest for this submission, such as allometric equations and carbon stock models based on ecological 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 ecological 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 ecological zones according to the scheme indicated in Table 9.

Table 9. Sample plots distributed among the ecological 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 ecological zones division are shown in Figure 3 above. The planned field sampling intensity over the pilot area of 9 ecological 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.

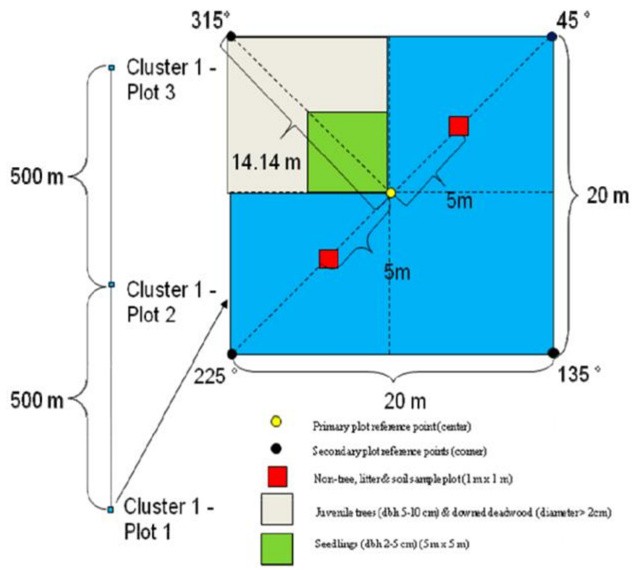


Figure 20. A sample cluster with sub-plots

Plots of 400 m^2 (20 x 20 meters) were established, as indicated in Figure 22. 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.

7.3 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.

7.3.1 Overview of carbon stock change estimation

The annual carbon stock change for the Forestry sector is estimated as the sum of changes in Forest lands and conversions to other land-use categories, as indicated below. Table 10 presents the land-use categories and sub-categories included in the estimation of the net emissions and removals.

Table 10 Land-use categories and sub-categories defined for the FRL/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 the Forest 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 11 shows the carbon pools included and excluded in the construction of the FREL/FRL.

Table 11. Carbon pools data sources

	Included
ΔC_{AB}	Yes
ΔC_{BB}	Yes
ΔC_{DOM}	Yes
ΔC_{SOC}	Yes
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.

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 Forest land remaining in the same land-use category

Annual change in carbon stocks in biomass in forest lands remaining forest lands (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 forest land remaining in the same land-use category (Equation 2.9, Ch2, V4)

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

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 12 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 12 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	0.5		2006 IPCC, V4, Ch5, pg.5.11, Step 4
	Perennial crops	0.5		2006 IPCC, V4, CH5, Section 5.2.1.4, Step 4; no error or range provided
	Fallow Lands	0.5		2006 IPCC, V4, CH5, Section 5.2.1.4, Step 4; no range or range provided
G	Grassland	0.47		2006 IPCC, V4, Ch6, page 5.29, Step 5.
W	Wetlands	0		Assumed to be zero
S	Settlements	0		Assumed to be zero
O	Other lands	0		Assumed to be zero

Table 13 provides the source of areas of land remaining in the same land-use category (ha) and period considered.

Table 13 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 (Figure 20). 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, were created to simplify the analysis as it sums up all plots with the same trajectory, represented in the same code, considerably reducing the number of plots for which IPCC equations were applied (Figure 21).

How do codes work?

Codes were created to quickly understand the land use changes and disturbances observed in Collect Earth plots. Codes are composed of three sections:

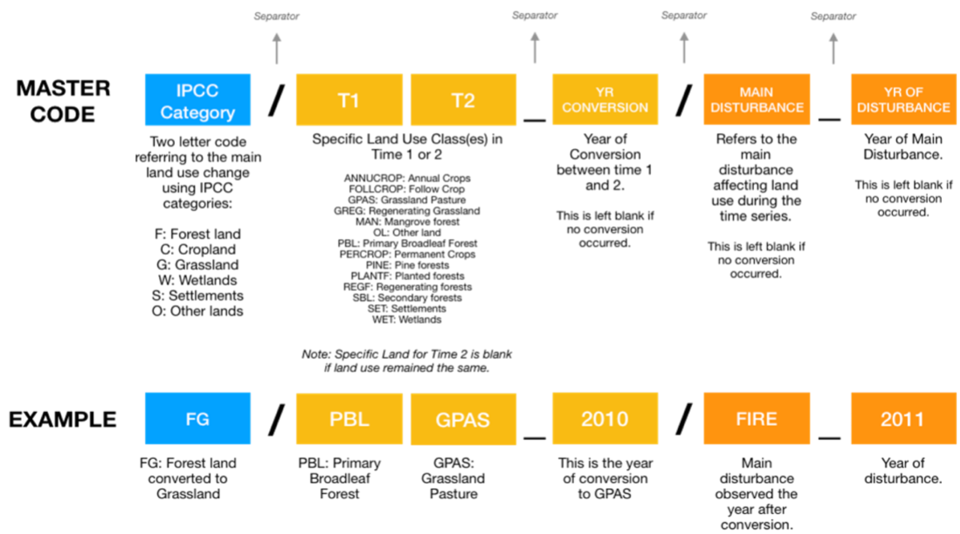
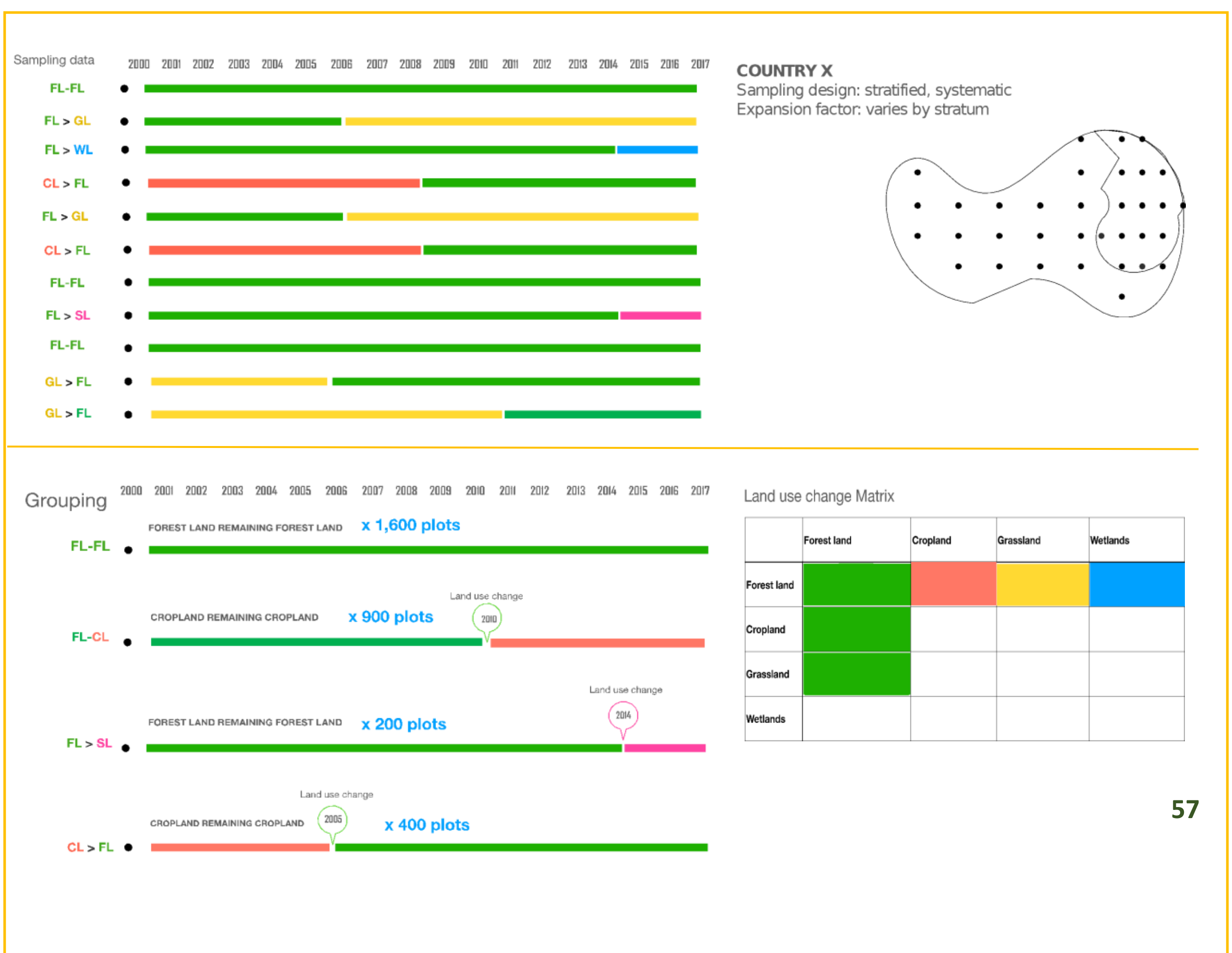


Figure 21 Land use and land use change code



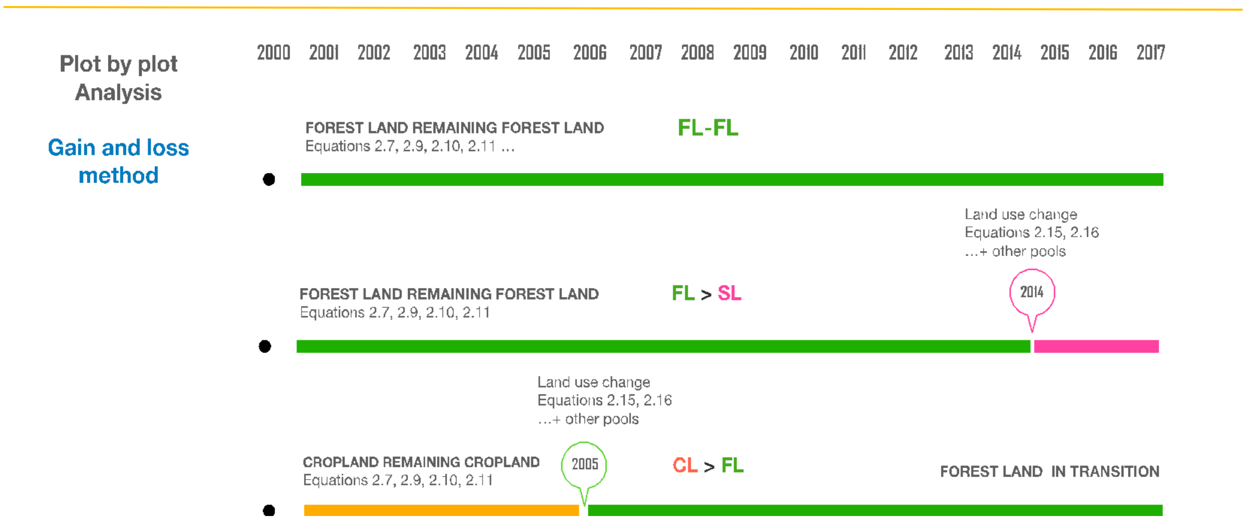


Figure 22 Plot by plot land use and land use change analysis

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 14 Expansion Factors by Strata (Vegetation Zone)

Row Labels	Count of Veg zone CODE NEW	Strata	Area per stratum (Ha)	Expansion Factor [Ha]
1	393			
FUPEVER.1	393	Upland evergreen 1x1	62,601	159
2	5250			
FMEVER.2	1393	Moist evergreen 2x2	886,983	637
FMSDECnw.2	1557	Moist SemiD NW 2x2	962,079	618
FMSDECse.2	1546	Moist SemiD SE 2x2	989,659	640
FWEVER.2	754	Wet evergreen 2x2	457,198	606
4	9636			
FMEVER.4	753	Moist evergreen 4x4	945,406	1,256
FMSDECnw.4	493	Moist SemiD NW 4x4	595,511	1,205
FMSDECnw.8	1			
FMSDECse.4	616	Moist SemiD SE 4x4	737,423	1,197
FWEVER.4	230	Wet evergreen 4x4	277,565	1,196
FWEVER.8	2			
8 (new 4x4)	10271		18000996	1753
FDRYfire.4 (1Ha plot)	563		986716	

FDRYfire.8 (0.5 Ha plot)	204		357531	
FDRYinn.4 (1 Ha plot)	383		671247	
FDRYinn.8 (0.5 Ha Plot)	144		252375	
FSAV.4 (1 Ha plot)	6481		11358627	
FSAV.8 (0.5 Ha Plot)	2340		4101093	
FSOUTH.4 (1 Ha plot)	117		205055	
FSOUTH.8 (0.5 Ha plot)	39		68352	
Grand Total	**18009**		**23,915,421**	

Then, to facilitate the understanding by Land-Use Classes, the Pivot table information was distributed by Forest Land, Cropland, Grassland, Wetlands, Settlements, Other Land) (Table 15). 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 15 Pivot Table of Land Use and Land-use Changes

Land use and Land Use change code	Number of plots	Area	Vegetation zone and sampling grid
CF/CANN>FDRYfire_2013/_/FDRYfire.4	1	1753	FDRYfire.4
CF/CANN>FDRYfire_2014/_/FDRYfire.4	1	1753	FDRYfire.4
CF/CANN>FDRYfire_2015/_/FDRYfire.4	1	1753	FDRYfire.4
CF/CANN>FDRYfire_2017/_/FDRYfire.4	3	5258	FDRYfire.4
CF/CANN>FDRYfire_2020/_/FDRYfire.4	1	1753	FDRYfire.4
CF/CANN>FDRYinn_2013/_/FDRYinn.4	1	1753	FDRYinn.4
CF/CANN>FDRYinn_2015/_/FDRYinn.4	1	1753	FDRYinn.4
CF/CANN>FDRYinn_2018/_/FDRYinn.4	1	1753	FDRYinn.4
CF/CANN>FDRYinn_2020/_/FDRYinn.4	1	1753	FDRYinn.4
CF/CANN>FMEVER_2012/_/FMEVER.2	1	637	FMEVER.2
CF/CANN>FMEVER_2015/_/FMEVER.2	1	637	FMEVER.2
CF/CANN>FMEVER_2015/_/FMEVER.4	1	1256	FMEVER.4
CF/CANN>FMSDECnw_2015/_/FMSDECnw.2	1	618	FMSDECnw.2
CF/CANN>FMSDECnw_2019/_/FMSDECnw.2	1	618	FMSDECnw.2
CF/CANN>FMSDECse_2010/_/FMSDECse.2	1	640	FMSDECse.2
CF/CANN>FMSDECse_2013/_/FMSDECse.2	1	640	FMSDECse.2
CF/CANN>FMSDECse_2014/_/FMSDECse.2	1	640	FMSDECse.2
CF/CANN>FMSDECse_2014/_/FMSDECse.4	1	1197	FMSDECse.4
CF/CANN>FMSDECse_2017/_/FMSDECse.2	1	640	FMSDECse.2

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 (Table 16). 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. Detailed LULUC matrices, including sub-categories of land use can be found in Annex I.

Table 16 Annual land use and land use change matrices 2000-2015 [Ha]

	Land Use and Land Use Change (LULUC) Vertical: Final Use Horizontal: Initial Use	Forest lands	Croplands	Grasslands	Wetlands	Settlements	Other Lands
2000	Forest lands	4,208,373	0	0	0	0	0
	Croplands	0	13847444	0	0	0	0
	Grasslands	0	0	4,359,734	0	0	0
	Wetlands	0	0	0	828,331	0	0
	Settlements	0	0	0	0	523538	0
	Other Lands	0	0	0	0	0	148001
							23,915,421

	Land Use and Land Use Change (LULUC) Vertical: Final Use Horizontal: Initial Use	Forest lands	Croplands	Grasslands	Wetlands	Settlements	Other Lands
2000 - 2001	Forest lands	4,208,373	0	0	0	0	0
	Croplands	0	13845692	1753	0	0	0
	Grasslands	0	1753	4,357,981	0	0	0
	Wetlands	0	0	0	828,331	0	0
	Settlements	0	0	0	0	523538	0
	Other Lands	0	0	0	0	0	148001
							23,915,421
2001-2002	Forest lands	4,207,115	1,258	0	0	0	0
	Croplands	0	13845692	0	0	0	1753
	Grasslands	0	1753	4,357,981	0	0	0
	Wetlands	0	0	0	828,331	0	0
	Settlements	0	0	0	0	523538	0
	Other Lands	0	0	0	0	0	148001
							23,915,421

2002-2003	*Forest lands*	4,201,711	1,898	1753	0	1753	0
	Croplands	0	13845197	1753	0	1753	0
	Grasslands	0	1258	4,356,105	0	618	0
	Wetlands	0	0	0	828,331	0	0
	Settlements	0	0	0	0	523538	0
	Other Lands	1753	0	640	0	0	147361
							23,915,421
2003-2004	*Forest lands*	4,199,322	2,389	0	0	1753	0
	Croplands	0	13848354	0	0	0	0
	Grasslands	1753	0	4,356,745	0	1,753	0
	Wetlands	0	0	0	828,331	0	0
	Settlements	0	0	0	0	527661	0
	Other Lands	0	0	0	0	0	147361
							23,915,421
2004-2005	*Forest lands*	4,191,632	4,741	1753	0	2949	0
	Croplands	0	13847793	1753	0	1197	0
	Grasslands	0	0	4,356,745	0	0	0
	Wetlands	0	0	0	828,331	0	0
	Settlements	0	0	0	0	531166	0
	Other Lands	0	0	0	0	0	147361
							23,915,421
2005-2006	*Forest lands*	4,187,017	3,334	1280	0	0	0
	Croplands	1753	13849576	0	0	1205	0
	Grasslands	0	0	4,358,498	0	1,753	0
	Wetlands	0	0	0	828,331	0	0
	Settlements	0	0	0	0	535312	0
	Other Lands	0	0	0	0	0	147361
							23,915,421

	Land Use and Land Use Change (LULUC) **Vertical: Final Use** **Horizontal: Initial Use**	*Forest lands*	*Croplands*	*Grasslands*	*Wetlands*	*Settlements*	Other Lands
2006-2007	*Forest lands*	4,184,702	3,131	0	0	159	777
	Croplands	0	13851675	618	0	618	0
	Grasslands	1753	0	4,358,025	0	0	0
	Wetlands	0	0	0	828,331	0	0
	Settlements	0	0	0	0	538270	0
	Other Lands	0	0	0	0	0	147361
							23,915,421
2007-2008	*Forest lands*	4,180,953	5,502	0	0	0	0
	Croplands	637	13850046	0	0	4123	0
	Grasslands	0	1753	4,356,891	0	0	0
	Wetlands	0	0	0	828,331	0	0
	Settlements	0	0	0	0	539047	0
	Other Lands	0	0	0	0	1753	146386
							23,915,421

2008-2009	Forest lands	4,167,195	8,977	5258	0	159	0
	Croplands	2950	13850206	3505	0	640	0
	Grasslands	1753	5258	4,348,128	0	1,753	0
	Wetlands	0	0	1753	826,579	0	0
	Settlements	0	0	0	0	544923	0
	Other Lands	0	1846	0	0	0	144540
							23,915,421
2009-2010	Forest lands	4,146,347	17,250	4795	0	1753	1753
	Croplands	2393	13856243	4145	0	1753	1753
	Grasslands	1753	3505	4,351,633	0	1,753	0
	Wetlands	0	0	3505	823,073	0	0
	Settlements	0	0	1753	0	545723	0
	Other Lands	0	0	0	0	0	144540
							23,915,421
2010-2011	Forest lands	4,129,947	17,238	796	0	2511	0
	Croplands	3505	13854891	8848	0	9754	0
	Grasslands	4123	10516	4,344,069	1,753	5,371	0
	Wetlands	0	0	0	823,073	0	0
	Settlements	0	0	1753	0	549228	0
	Other Lands	0	1753	0	0	0	146293
							23,915,421
2011-2012	Forest lands	4,110,467	22,326	3505	0	1277	0
	Croplands	4142	13873245	3505	0	3505	0
	Grasslands	7010	2393	4,337,846	3,505	1,205	3505
	Wetlands	1753	2393	1753	818,928	0	0
	Settlements	0	0	0	0	566864	0
	Other Lands	0	618	0	0	0	145675
							23,915,421

	Land Use and Land Use Change (LULUC) Vertical: Final Use Horizontal: Initial Use	Forest lands	Croplands	Grasslands	Wetlands	Settlements	Other Lands
2012-2013	Forest lands	4,099,607	17,708	1753	0	1912	2393
	Croplands	9403	13864335	7660	0	19576	0
	Grasslands	3505	12268	4,329,083	0	1,753	0
	Wetlands	0	1753	0	820,681	0	0
	Settlements	1256	0	0	0	571596	0
	Other Lands	640	618	1753	0	0	146169
							23,915,421
2013-2014	Forest lands	4,079,352	27,203	4702	0	1256	1898
	Croplands	5983	13860597	17218	1753	11132	0
	Grasslands	11134	11240	4,309,668	0	6,455	1753
	Wetlands	0	0	0	817,672	1256	1753
	Settlements	0	640	0	0	594196	0
	Other Lands	618	0	1753	0	0	146192
							23,915,421

2014-2015	Forest lands	4,068,905	21,219	4430	0	1277	1256
	Croplands	6015	13861461	19465	159	12578	0
	Grasslands	13474	7010	4,309,907	0	1,197	1753
	Wetlands	0	0	0	817,672	0	1753
	Settlements	0	1753	0	0	612541	0
	Other Lands	640	0	0	0	0	150955
							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 also include the belowground biomass growth.

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

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 (Table 17), based on the weights of open and closed forests (Table 18).

Table 17 Weighted average annual above-ground biomass growth for each land-use category and sub-category, in tonnes d.m. ha-1 yr-1.

GW = Weighted Average Annual Above-ground Biomass Growth, tonnes d. m. ha^{-1} yr^{-1}				
LU	Sub-Category	Value	Range / Error	Notes
F	Wet Evergreen	12.94	± 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	14.66	± 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	7.39	± 0.21%	AGB/20 years; same calculation as indicated for Wet Evergreen.

	Dry Semideciduous (Fire Zone)	1.59	± 1.09%	AGB/20 years; same calculation as indicated for Wet Evergreen.
	Dry Semideciduous (Inner Zone)	2.40	± 0.81%	AGB/20 years; same calculation as indicated for Wet Evergreen.
	Savannah	1.78	± 0.52%	AGB/20 years; same calculation as indicated for Wet Evergreen.
	Southern Marginal	1.13	± 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	8.84		2019 IPCC refinement, Vol. 4. Ch5, Table 5.1 Tropical, fallow
G	Grassland	24.43		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%; 2.4% and 0.1%, respectively.
W	Wetlands	0		Assumed zero
S	Settlements	0		Assumed zero
O	Other lands	0		Assumed zero

Clarification Note:

Gw – Forest lands:

Forest Gw was estimated as a weighted average of the annual above-ground biomass growth in open and closed forests. The percentage distribution is shown in Table 18.

Table 18 Percentage distribution between open and closed forest [12]

Vegetation Zone	Closed/Open	Percentage
Wet Evergreen (WETVER)	Open	**2.6%**
	Closed	**97.4%**
Moist Evergreen (MEVER)	Open	**1.5%**
	Closed	**98.5%**
Moist Semi-deciduous SE (MSEMSE)	Open	**5.1%**
	Closed	**94.9%**

[12] Data from 2020 was used for the calculation

Moist Semi-deciduous NW (MSEMNW)	Open	**4.1%**
	Closed	**95.9%**
Upland Evergreen (UPEVER)	Open	**7.8%**
	Closed	**92.2%**
Dry Semidecidouos (Fire Zone) Forest	Open	**9.3%**
	Closed	**90.7%**
Dry Semidecidouos (Inner Zone) Forest	Open	**6.5%**
	Closed	**93.5%**
Savannah Forest	Open	**20.8%**
	Closed	**79.2%**
Southern Marginal Forest	Open	**21.4%**
	Closed	**78.6%**

Closed Forest has =>60% canopy, 1 ha and minimum height of 5m, Open forest has < 59%-15% canopy cover, 1 ha and minimum height of 5m

Annual growth rate was estimated as above-ground biomass divided by 20 (Table 19), using the Tier 1 assumption that stability of all forest types will be reached at 20 years. This assumption was validated by the Forestry Commission, Ghana team.

Table 19 Above- ground biomass annual growth for Open and Closed forests in 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 / Disturbance
	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 / Disturbance
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	12.94		

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 / Disturbance
	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 / Disturbance
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	14.66		
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 / Disturbance
	Closed - Disturbed (Fire, logging, Other Disturbances)	13.14	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F / Disturbance
	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 / Disturbance
	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 / Disturbance
	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 / Disturbance
	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 / Disturbance
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	7.39		

Dry Semi deciduous (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 / Disturbance
	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 / Disturbance
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	1.59		
Dry Semi deciduous (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	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F / Disturbance
	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 / Disturbance
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	2.40		
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 / Disturbance
	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 / Disturbance
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	1.78		
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 / Disturbance
	Closed - Disturbed (Fire, logging, Other Disturbances)	1.19	CE / Estimated	Assumed a linear growth of the aboveground biomass in 20 years after conversion to F / Disturbance
	Weighted Average - Disturbed (Fire, logging, Other Disturbances)	1.13		

As an example of calculation, the value 12.94 t d.m. ha^{-1} yr^{-1} for Wet Evergreen in Table 20 is calculated as follows:

From **Table 18**: % open = 2.6%; % closed = 97.4%

From **Table 19:** 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: (0.026 x 3.22 + 0.974 x 13.20) = 12.94 t d.m. ha^{-1} yr^{-1}.

The standard deviation in Table 4.8 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).

When applying equation 2.9 of the 2006 IPCC GLs, a slight modification was introduced since logging statistics were used and are not spatially explicit, making it impossible to separate the plots affected by logging from those not affected (in which case the Gw for undisturbed forest would be used). However, FC team knows that not all forests are affected in the same way by logging, the reason why an fd value was estimated based on the Collect Earth assessment of areas affected by logging. Therefore, gains are only applied to the section that was disturbed (e.g 10%, 20%), instead to the entire plot. In this way, over-estimations due to gains are avoided.

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.

- 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}** (5.34 t d.m. ha^{-1} yr^{-1}, using CF = 0.5 as indicated in Table 12**).**

The literature reviewed can be found in Annex II

Gw - Grasslands:

Gw was estimated as a weighted average of the annual above-ground biomass by climate zones. The percentage distribution is shown in table 20.

Table 20 Percentage distribution of grasslands by climate zone [13]

[13] Data from 2020 was used for the calculation

Row Labels	Sum of Area (Ha)	%	Climate Zone	Total %	Total % of the Veg Zones with AGB values
Dry semideciduous (fire zone)	161240	3.7%	Dry		3.7%
Dry semideciduous (inner zone)	59589	1.4%	Dry		
Savannah	4009958	92.1%	Dry		92.1%
Southern marginal	14021	0.3%	Dry	97.5%	0.3%
Moist evergreen	20869	0.5%	Moist		
Moist semideciduous (north west subtype)	32247	0.7%	Moist		0.7%
Moist semideciduous (south east subtype)	50828	1.2%	Moist		
Upland evergreen	1434	0.0%	Moist	2.4%	
Wet evergreen	5445	0.1%	Wet	0.1%	
Total	4355630			100.0%	96.8%

For grassland, the average annual aboveground biomass growth was estimated using the estimates provided by the Forest Permanent Plot, reproduced in Table 21.

Table 21 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
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

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 20). 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 0.037) + (12.0 x 0.921) + (1.09 x 0.003) + (1.09 x 0.007)] = 11.10 tC ha^{-1}.

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.

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 22 provides the summary results which are detailed in sequence.

Table 22 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: BGB : ABG Ratio				
LU	**Sub-Category**	**Value**	**Range / Error**	**Source**
F	Wet Evergreen	0.065	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, BGB/AGB
	Moist Evergreen	0.168	NE	Weighted average open and closed, BGB/AGB
	Moist Semideciduous SE	0.188	NE	Weighted average open and closed, BGB/AGB
	Moist Semideciduous NW	0.381	NE	Weighted average open and closed, BGB/AGB
	Upland Evergreen	0.326	NE	Weighted average open and closed, BGB/AGB
	Dry Semideciduous (Inner Zone)	0.049	NE	Weighted average open and closed, BGB/AGB
	Dry Semideciduous (Fire Zone)	0.638	NE	Weighted average open and closed, BGB/AGB
	Savannah	0.058	NE	Weighted average open and closed, BGB/AGB
	Southern Marginal	1.392	NE	Weighted average open and closed, BGB/AGB
C	Annual crops	0	NE	Assumption that the R is zero
	Perennial crops	0.17	NE	BGB/AGB
	Fallow Lands	0.29	NE	BGB/AGB
G	Grassland Dry	2.77	NE	Weighted average dry and moist/wet IPCC V4, Ch6, Table 6.1 grasslands

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:

R - Grassland

Root-to-shoot ratio for Grassland was calculated using the IPCC defaults by Climate Zone, multiplied by the percentage distribution, then the total sum was used as a single value for all grasslands (Table 23).

Table 23 Estimation of the root-to-shoot ratios for Grassland.

Row Labels	%	R [tonne d.m. below- ground biomass (tonne d.m. above-ground biomass) -1]	Weighted R	Climate Zone
Dry semideciduous (fire zone)	3.7%	2.80	0.104	Dry
Dry semideciduous (inner zone)	1.4%	2.80	0.038	Dry
Savannah	92.1%	2.80	2.578	Dry
Southern marginal	0.3%	2.80	0.009	Dry
Moist evergreen	0.5%	1.60	0.008	Moist
Moist semideciduous (north west subtype)	0.7%	1.60	0.012	Moist
Moist semideciduous (south east subtype)	1.2%	1.60	0.019	Moist
Upland evergreen	0.0%	1.60	0.001	Moist
Wet evergreen	0.1%	1.60	0.002	Wet
Sum Total			**2.769**	

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)$^{-1}$

The Resource Management and Support Centre of the Forestry Commission, and the Energy Commission were the primary sources of data on industrial round wood and fuelwood harvesting (Table 24 and Table 25). The industrial round wood data were segregated into “planned logging” and “unplanned logging”. The planned logging refers to permitted systematic and supervised extraction of timber. Unplanned logging is unsupervised removal of timber and unaccounted for in official records. However, this is relevant because the resulting impact on the forest stocks is severe.

Table 24 Annual carbon loss in biomass of wood removals (tonnes C yr^{-1}).

H = annual wood removals, roundwood, tonnes C yr^{-1}				
Years	**Harvesting (m3/yr) - Logging**			**Source**
	Planned logging	**Unplanned logging**	**Total logging production**	
2000	982,955	837,332	1,820,287	Table 78 Quantities of wood harvesting grouped according to types between 1990 and 2016 (NIR 2019)[14]
2001	1,245,526	1,061,004	2,306,530	
2002	1,364,392	1,162,260	2,526,651	
2003	1,177,482	1,003,040	2,180,523	
2004	902,232	768,568	1,670,800	
2005	934,886	796,384	1,731,270	
2006	858,861	731,623	1,590,484	

14 GHG Inventory Source: https://unfccc.int/sites/default/files/resource/gh_nir4_rev_0.pdf

2007	878,498	748,350	1,626,848	
2008	898,161	765,100	1,663,261	
2009	760,953	648,219	1,409,172	
2010	901,154	767,650	1,668,804	
2011	816,421	695,469	1,511,890	
2012	864,413	736,352	1,600,765	
2013	1,012,557	862,549	1,875,106	
2014	957,272	815,454	1,772,726	
2015	778,226	662,933	1,441,159	

Clarification notes

The Biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark) ($BCEF_R$) of 1.67 tonnes of biomass removals (m3 of removals) $^{-1}$ was taken from the GHG inventory. Data was provided by the Forestry Commission, Ghana.

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:

$Lf_{uelwood}$ = 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 25 Annual carbon loss in biomass of fuelwood removal

FG_{trees} = annual volume of fuelwood removal of whole trees, m^3 yr^{-1}				
FG_{part} = annual volume of fuelwood removal as tree parts, $m^3 yr^{-1}$				
Years	**Harvesting (m3/yr) Fuelwood (FW)**			**Source**
	Total FW	**Fraction as whole**	**Fraction as part**	
2000	204,635.34	122,781.20	81,854.13	Table 78 Quantities of wood harvesting grouped according to types between 1990
2001	222,263.10	133,357.86	88,905.24	
2002	230,693.77	138,416.26	92,277.51	
2003	239,124.44	143,474.66	95,649.77	
2004	242,956.56	145,773.94	97,182.62	
2005	248,321.53	148,992.92	99,328.61	
2006	470,232.07	282,139.24	188,092.83	

2007	465,250.31	279,150.19	186,100.13	and 2016 (NIR 2019)[15]
2008	465,848.13	279,508.88	186,339.25	
2009	474,662.01	284,797.20	189,864.80	
2010	487,016.77	292,210.06	194,806.71	
2011	511,971.55	307,182.93	204,788.62	
2012	517,919.00	310,751.40	207,167.60	
2013	540,206.63	324,123.98	216,082.65	
2014	551,672.34	331,003.40	220,668.94	
2015	549,986.20	329,991.72	219,994.48	

Clarification notes

The Biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark) ($BCEF_R$) of 1.67 tonnes of biomass removals (m3 of removals) $^{-1}$ was taken from the GHG inventory. Data was provided by the Forestry Commission of Ghana.

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

Area affected by disturbances

Forest land, cropland and grassland biomass consumption by fires is an important source of emissions in Ghana. The areas affected by fire in the different ecological zones were estimated from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data. Emissions from burnt areas are a function of the area burnt, frequency of fire events, the type and amount of fuel load available. The prevailing weather conditions at the time of burning are also important in determining the amount of emissions. Table 26 shows the respective fractions of areas of land categories affected by annual fires in forest lands in Ghana from 2000 to 2015.

Table 26 Area affected by disturbances [fires], ha yr-1

[15] GHG Inventory Source: https://unfccc.int/sites/default/files/resource/gh_nir4_rev_0.pdf

Adisturbance = area affected by disturbances, ha yr-1		
Year	Forest Land	Source
2000	135,692	Assumed a specified percentage per ecological zone
2001	135,692	
2002	135,667	
2003	135,576	
2004	135,535	
2005	135,288	
2006	135,291	
2007	135,313	
2008	135,204	
2009	134,814	
2010	134,024	
2011	133,918	
2012	133,555	
2013	133,579	
2014	133,355	
2015	135,515	

Table 27 Assumptions per ecological zones for areas affected by disturbances [fires], ha yr-1

Ecological Zone	Assumption
Wet Evergreen Forest	Assumed as 1% of total available forest (FC)
Moist Evergreen Forest	Assumed as 1% of total available forest (FC)
Moist Semi-deciduous SE Forest	Assumed as 2% of total available forest (FC)
Moist Semi-deciduous NW Forest	Assumed as 2% of total available forest (FC)
Upland Evergreen Forest	Assumed as 1% of total available forest (FC)
Dry Semidecidouos (Fire Zone) Forest	Assumed as 3% of total available forest (FC)
Dry Semidecidouos (Inner Zone) Forest	Assumed as 3% of total available forest (FC)
Savannah Forest	Assumed as 5% of total available forest (FC)
Southern Marginal Forest	Assumed as 2% of total available forest (FC)

Average above-ground biomass

Biomass stock data were sourced from the FPP forest inventory report (see section on National Forest Inventory). The data included carbon stocks for the five main biomass pools (above-ground biomass, dead wood, litter, herbs and soil) in the ten different ecological zones of Ghana. The carbon stocks for the individual pools were averaged for each ecological zone to represent forest land, cropland and grassland.

Aboveground biomass was estimated as weighted average between open and closed forests (Table 29). To estimate the weighted average the percentages of open and closed forests from each vegetation zone in Table 19 are used, jointly with data from Table 28, which provides the above-ground biomass for open and closed forests for each ecological zone.

Table 28 Weighted average above-ground biomass of land areas affected by disturbances, tonnes d.m. ha-1

BW = average above-ground biomass, tonnes d.m. ha-1				
LU	**Sub-Category**	**Value**	**Range / Error**	**Notes**
F	Wet Evergreen	258.80	± 1.66	Weighted average open/closed forest
	Moist Evergreen	293.26	± 0.38	Weighted average open/closed forest
	Moist Semideciduous SE	253.32	± 1.83	Weighted average open/closed forest
	Moist Semideciduous NW	83.87	± 0.21	Weighted average open/closed forest
	Upland Evergreen	146.76	± 1.00	Weighted average open/closed forest
	Dry Semideciduous (Fire Zone)	31.84	± 1.13	Weighted average open/closed forest
	Dry Semideciduous (Inner)	48.09	± 0,06	Weighted average open/closed forest
	Savannah	35.66	± 0.05	Weighted average open/closed forest
	Southern Marginal	22.55	± 14.79	Weighted average open/closed forest
C	Annual crops	10		2006 IPCC, V4, Ch5, pg.5.11, Step 4
	Perennial crops	106.720		Weighted average aboveground biomass: Rubber, Cocoa, Oil Palm, Other permanent.
	Fallow Lands	44.2		2019 IPCC refinement, Vol. 4. Table 5.1, Tropical, Fallow
G	Grasslands	22.93		Weighted Average by Vegetation Zone
W	Wetlands	0		NA
S	Settlements	0		NA
O	Other lands	0		NA

Clarification Notes:

Bw- Forest lands:

The aboveground biomass estimates in Table 29 for open and closed forests in each vegetation zone are country-specific estimates obtained from the Forest Preservation Programme.

Table 29 Estimates of aboveground biomass (AGB) by vegetation zone and forest type (t d.m. ha-1) and weighted average for each vegetation zone

BW = average above-ground biomass, tonnes d.m. ha-1

Vegetation Zone	Canopy	AGB (tdm/Ha)	Error	Source
Wet Evergreen (WETVER)	Open	**64.41**	NA (n=0)	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Closed	**264,02**	(n=5); CI: + 0.69%	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Weighted Average	**258.80**	± 1.66	Estimated by Percentage distribution
Moist Evergreen (MEVER)	Open	**84.72**	(n=6); CI: + 1.22%	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Closed	**296.52**	(n=30); CI:0.11%.	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Weighted Average	**293.26**	± 0.38	Estimated by Percentage distribution
Moist Semi-deciduous SE (MSEMSE)	Open	**74.85**	(n=7); CI: + 3.56%	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Closed	**262.86**	(n=9) CI: + 0.67%	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Weighted Average	**253.32**	± 1.83	Estimated by Percentage distribution
Moist Semi-deciduous NW (MSEMNW)	Open	**37.14**	(n=24) CI: + 0.90%	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Closed	**85.88**	(n=45) CI: + 0.24%	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Weighted Average	**83.87**	± 0.21	Estimated by Percentage distribution
Upland Evergreen (UPEVER)	Open	**55.71**	(n=6) CI: + 3.82%	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Closed	**155.51**	(n=15) CI: + 0.58%	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Weighted Average	**147.76**	± 1.00	Estimated by Percentage distribution
Dry Semidecidouos (Fire Zone) Forest	Open	**25.53**	(n=11) CI: + 3.01%	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Closed	**32.50**	(n=1)	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Weighted Average	**31.84**	± 1.13	Estimated by Percentage distribution
Dry Semidecidouos (Inner Zone) Forest	Open	**30.17**	(n=9) CI: + 5.10%	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Closed	**49.32**	(n=1)	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Weighted Average	**48.09**	± 0,06	Estimated by Percentage distribution
Savannah Forest	Open	**27.85**	(n=12) CI: + 2.03%	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Closed	**37.72**	(n=0)	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Weighted Average	**35.66**	± 0.05	Estimated by Percentage distribution
Southern Marginal Forest	Open	**17.99**	(n=4) CI: + 35.69%	FPP Table, 4.8 (See Step 5a NFI Biomass)

	Closed	**23.79**	(n=3) CI: + 65.37%	FPP Table, 4.8 (See Step 5a NFI Biomass)
	Weighted Average	**22.55**	± 14.79	Estimated by Percentage distribution

The programme developed several allometric equations for Dry, Moist and Wet zones in Ghana. The equations presented in Table 30a 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). Table 30b 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 31 and used to estimate the root-to-shoot ratios in open and closed forests for each ecological zone.

Table 30 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 31 Below-ground biomass by vegetation zone and canopy

Vegetation Zone	Canopy	BGB (tdm/ha)
Wet Evergreen (WETVER)	Open	**12.9**
	Closed	**16.8**
	Weighted Average	**16.72**
Moist Evergreen (MEVER)	Open	**6.4**
	Closed	**49.9**
	Weighted Average	**49.23**
Moist Semi-deciduous SE (MSEMSE)	Open	**16.2**
	Closed	**49.3**
	Weighted Average	**47.64**
Moist Semi-deciduous NW (MSEMNW)	Open	**19.1**
	Closed	**32.5**
	Weighted Average	**31.94**

Upland Evergreen (UPEVER)	Open	**27.3**
	Closed	**49.9**
	Weighted Average	**48.15**
Dry Semidecidouos (Fire Zone) Forest	Open	**16.8**
	Closed	**0.0**
	Weighted Average	**1.57**
Dry Semidecidouos (Inner Zone) Forest	Open	**21.5**
	Closed	**31.3**
	Weighted Average	**30.70**
Savannah Forest	Open	**9.9**
	Closed	**0.0**
	Weighted Average	**2.06**
Southern Marginal Forest	Open	**14.5**
	Closed	**36.0**
	Weighted Average	**31.38**

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.

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 18: % open = 2.78% ; % closed = 97.22%

From Table 30: 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) = 258.80 t d.m. ha^{-1}.

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}**). Annex II provides estimates for above-ground biomass for the main crops in Ghana (cocoa, oil palm, rubber, citrus, cashews etc.)

Bw - Grassland:

For Grassland, the above-ground biomass is equal to the estimate provided in Table 21 (Average annual above-ground biomass growth for Grasslands), since under Tier 1, the 2006 IPCC GLs (Chapter 6, section 6.3.1.1, page 6.25) it is assumed that grasslands achieve their steady-state biomass during the first year following conversion, so there is only a single year of biomass growth.

Fraction of biomass lost in disturbance (fd)

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 with 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 and are presented in table 32. The information observed in CE was crosschecked with National Experts *(see Expert Judgement Table # 1, attached Excel file).*

Table 32 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

Forest land converted to and from other land-use categories

This session provides the information, emission factors and parameters necessary to estimate emissions and removals for **land converted to and from another land-use categories**. 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 and other land-use categories converted to Forest.

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 forest land remaining in the same category.

Clarification notes

After conversion, the Gw is applied until the forest reaches stability (maximum stock) (Table 33). Once the time has been reached, Gw=0.

Table 33 annual increase in carbon stocks in biomass due to growth on land converted to another land-use category, in tonnes C yr-1

Notation	*Gw (remaining)*	*GTOTAL (Remaining)*	*Gw (after disturbance/conversion)*	*GTOTAL (after disturbance/conversion)*	*GTOTAL[C] (after disturbance/conversion)*	*Time to reach max Stock*
Parameter	**Biomass Growth**	**Annual Biomass Increase 2.10 GTOTAL=∑(Gw • (1+R))**	**Biomass Growth**	**Annual Biomass Increase 2.10 GTOTAL=∑(Gw • (1+R))**	**Annual Carbon Increase 2.10 GTOTAL=∑(Gw • (1+R)) *Cf**	
Units	**[t d.m. / ha / yr]**	**[t.d.m /ha]**	**[t d.m. / ha / yr]**	**[t.d.m /ha/yr]**	**tC ha/yr**	**[Years]**
Forestland						
Wet Evergreen (WETVER)	0.00	0.00	12.94	13.78	6.47	20
Moist Evergreen (MEVER)	0.00	0.00	14.66	17.12	8.05	20
Moist Semi-deciduous SE (MSEMSE)	0.00	0.00	12.67	15.05	7.07	20
Moist Semi-deciduous NW (MSEMNW)	0.00	0.00	4.19	5.79	2.72	20
Upland Evergreen (UPEVER)	0.00	0.00	7.39	9.80	4.60	20
Dry Semidecidouos (Fire Zone) Forest	0.00	0.00	1.59	1.67	0.79	20
Dry Semidecidouos (Inner Zone) Forest	0.00	0.00	2.40	3.94	1.85	20
Savannah Forest	0.00	0.00	1.78	1.89	0.89	20

Southern Marginal Forest	0.00	0.00	1.13	2.70	1.27	20

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

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

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, DA_{TO_OTHER}, is provided in Table 34. 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 the pivot table with area estimation for each land use conversion.

Table 34 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 35 for annual Gw values. These values will be allocated annually to each land use until maximum biomass stock is reached.

Notes:

- **For land converted to Forest**. B_{after} was allocated as the stock of a forest of 10 years (Gw x 10), as defined as an approximate time when a forest could reach the forest definition and could be identified to image interpretation (Collect Earth). In this way, the maximum stock is not allocated, but a value representing a younger forest.

Table 35 Biomass stocks on land before the conversion and immediately after the conversion

Notation	*AGB - BW*	*B_BEFORE*	*Time to reach max Stock*	*Years after conversion to reach forest definition / LU*	*B_AFTER*
Parameter	**Above Ground Biomass**	**To use in Eq 2.14, 2.16 (AGB+ BGB)* CF**			**To use in Eq 2.14, 2.16 (AGB+ BGB)* CF**
Units	**[t.d.m/ ha]**	**[tC / ha]**	**[Years]**	**[Years]**	**[tC / ha]**
Forestland					
Wet Evergreen (WETVER)	258.80	129.50	20.00	10.00	64.75
Moist Evergreen (MEVER)	293.26	160.97	20.00	10.00	80.49
Moist Semi-deciduous SE (MSEMSE)	253.32	141.46	20.00	10.00	70.73
Moist Semi-deciduous NW (MSEMNW)	83.87	54.43	20.00	10.00	27.22
Upland Evergreen (UPEVER)	147.76	92.08	20.00	10.00	46.04
Dry Semidecidouos (Fire Zone) Forest	31.84	15.71	20.00	10.00	7.85
Dry Semidecidouos (Inner Zone) Forest	48.09	37.03	20.00	10.00	18.51
Savannah Forest	35.66	17.73	20.00	10.00	8.86
Southern Marginal Forest	22.55	25.34	20.00	10.00	12.67
Croplands					
Annual (CANN)	10	5	1	1	0.0
Perennial (CPER)	106.7	62.6	20	5	15.6
Fallow (CFA)	44.2	28.5	5	3	17.1
Grassland (GRASS)	22.93	40.95	1.00	1.00	0.00
Wetlands (WET)	0.00	0.00	NA		0.00
Settlement (SSET)	0.00	0.00	NA		0.00
Other Lands (OTHER)	0.00	0.00	NA		0.00

- **For Forest lands converted to 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 Forest lands converted to Grasslands:** According with the 2006 IPCC GLs, volume 4, chapter 6 (Grasslands), page 6.25, as a simplification for Tier 1, it is assumed that all biomass is lost immediately from the previous ecosystem after conversion (Equation 2.16) , even when there is no abrupt change, and residual biomass (B_{AFTER}) is thus assumed to be zero, (i.e., the land is cleared of all vegetation before grassland vegetation is established). Thus, there is no transfer of biomass from the biomass pool to the dead wood pool.

- **For Forest lands converted to 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 Forest lands converted to 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 Forest lands converted to For Other Land:** According to 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 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 35 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 Forest land remaining in the same land-use category

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

The Tier 1 assumption for both deadwood and litter pools for forest lands 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 forest 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)

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

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 36 provides the weighted average estimates of carbon content in litter and deadwood. This information was provided by the FC. The standard deviations for each estimated value zone are also provided.

Table 36 Weighted averages of carbon stocks in litter and deadwood for each vegetation zone, tonnes C ha^{-1}.

LU	Sub-Category	Value Litter	St. Dev	Value Deadwood	St. Dev.
F	Wet Evergreen	2.69	2.42	21.77	2.42
	Moist Evergreen	2.15	2.88	43.71	2.88
	Moist Semideciduous SE	1.89	1.61	50.93	1.61
	Moist Semideciduous NW	1.97	2.10	91.56	2.10
	Upland Evergreen	1.25	1.06	195.38	1.06
	Dry Semideciduous (Fire Zone)	0.72	1.26	25.91	1.26
	Dry Semideciduous (Inner)	1.80	1.51	38.14	1.51
	Savannah	1.13	3.00	19.59	3.00
	Southern Marginal	0.97	1.13	1.05	1.13
C	Annual crops	0	0	0	0
	Perennial crops	0	0	0	0
	Fallow Lands	0	0	0	0
G	Grasslands	0	0	0	0
W	Wetlands	0	0	0	0
S	Settlements	0	0	0	0
O	Other lands	0	0	0	0

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.

Change in Carbon stock in soils in Forest land remaining in the same land category

It is assumed in the Tier 1 method that forest soil C stocks do not change with management.

Change in Carbon stock in soils in land converted to a new land category

Annual change in carbon stocks in mineral soils, tonnes C yr-1 (Equation 2.25, Ch2, V4)

$$\Delta CMineral = \frac{(SOCo - SOC_{o-t})}{D}$$

$$\Delta SOC = \sum_{c,s,i} \{(SOC_{REF} * F_{LU} * F_{MG} * F_I * A$$

Where,

$\Delta C_{Mineral}$ = annual change in carbon stocks in mineral soils, tonnes C yr^{-1}

SOC0 = soil organic carbon stock in the last year of an inventory time period, tonnes C
SOC(0-T) = soil organic carbon stock at the beginning of the inventory time period, tonnes 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 zones, *s* the soil types, and *i* the set of management systems that are present in a country.

SOCREF = the reference carbon stock, tonnes C ha^{-1}

FLU = stock change factor for land-use systems or sub-system for a particular land-use, dimensionless

FMG = stock change factor for management regime, dimensionless

FI = stock change factor for input of organic matter, dimensionless

A = land area of the stratum being estimated, ha.

For Tier 1, the initial (pre-conversion) soil organic C stock (SOC(0-T)) and C stock in the last year of the inventory time period (SOC0) are determined from the common set of reference soil organic C stocks (SOC_{REF}) and default stock change factors (F_{LU}, F_{MG}, F_I) as appropriate for describing land use and management both pre- and post-conversion.

Soil information was obtained from the Global Soil Organic Carbon Map -GSOCmap-, from FAO (2019). The web address of the portal is http://54.229.242.119/GSOCmap/. The country was selected, and information was downloaded through the “crop & Download” function. The result of the process is a TIFF file. The TIFF image processing was done in QGIS Desktop version 2.18.15. Ghana has information on land uses obtained through Collect earth assessment described in the activity data section. Thus, the objective is to link the SOC information for each of the plots, which will then allow allocating the SOC ref value by land use and sub-categories of land use. The TIFF image was then vectorized and later converted to a shape file. Where the value of SOC ton ha is preserved.

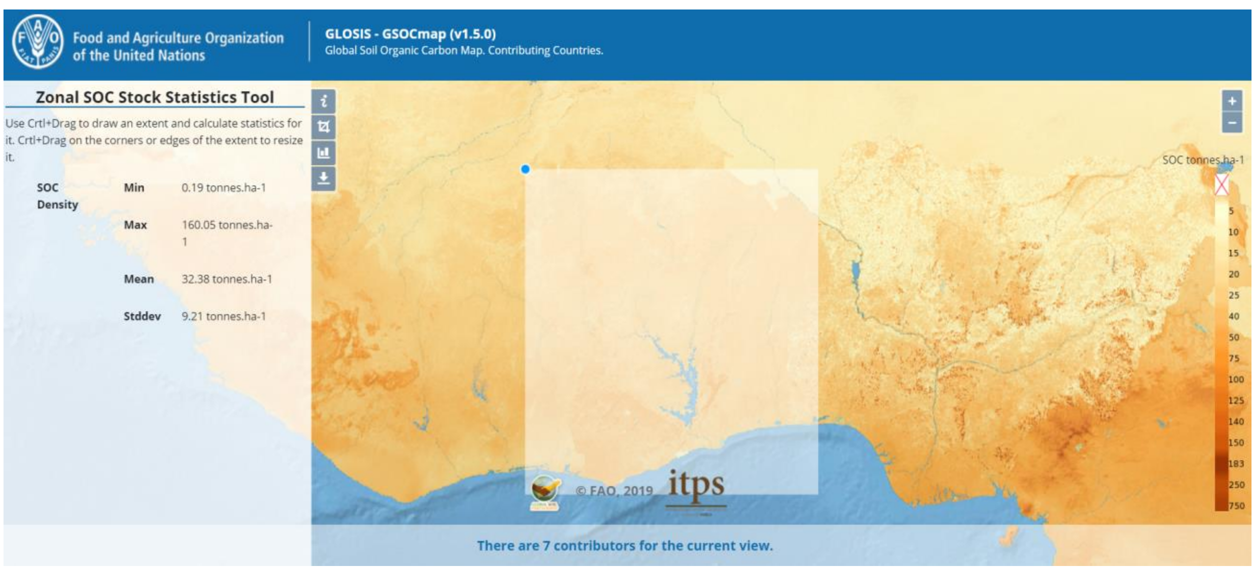


Figure 23 Global Soil Organic Carbon Map (FAO 2019) – Ghana

Subsequently, the plots CSV file is uploaded, which contains the information of the plots (coordinates, plot ID, land use type, etc). This file is also converted to a shapefile. Once both layers of information are added and activated on QGIS, the plots over the soil information can be visualized. Subsequently, the processing tool “Intersection” is applied. Information was saved as a CSV file. The result of this process is a SOC value for each plot. Then, information is organized by land use and sub-category and an average value is estimated

Table 37 Soil Organic Carbon reference value by vegetation zones

Vegetation Zone	SOC ref [t Cha]
Wet Evergreen (WETVER)	**55.62**
Moist Evergreen (MEVER)	**48.52**
Moist Semi-deciduous SE (MSEMSE)	**48.13**
Moist Semi-deciduous NW (MSEMNW)	**50.35**
Upland Evergreen (UPEVER)	**49.92**
Dry Semidecidouos (Fire Zone) Forest	**42.32**
Dry Semidecidouos (Inner Zone) Forest	**43.61**
Savannah Forest	**31.65**
Southern Marginal Forest	**40.820**
Annual (CANN)	**35.17**
Perennial (CPER)	**45.12**
Fallow (CFA)	**39.35**
Grasslands	**32.09**

Table 38 Default Stock change factors (FLU, FMG, FI) were selected for forestlands, croplands and grasslands

		Value	Forest lands	Croplands	Grasslands
Factor for land use systems	FLU	1	IPCC 2006, Vol 4, Ch 4, pg 4Tier 1. For Forest land Soil C stocks are assumed equal to the reference values, management and input factors equal 1	IPCC 2006. Table 5.5, Ch. 5, FLU, Long term cultivated, tropical, Dry / all perennial types/et aside, tropical, Dry	IPCC 2006. Table 6.2, Ch. 6, FLU, All
Factor for management regime	FMG	1		IPCC 2006. Table 5.5, Ch. 5, FMG, Full tillage, all types	IPCC 2006. Table 6.2, Ch. 6, FMG, Nominally managed (non – degraded), All climate regimes
Factor for input of organic matter	FI	1		IPCC 2006. Table 5.5, Ch. 5, FI, Low, tropical Dry	IPCC 2006. Table 6.2, Ch. 6, FI, Medium, all climate regimes

Estimation of Greenhouse Gas Emissions from Fire (equation 2.27)

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

Where:

L_{fire} = amount of greenhouse gas emissions from fire, tonnes of each GHG (CH4, N2O).
A = area burnt, ha
M_B = mass of fuel available for combustion, tonnes ha^{-1}
C_f = combustion factor, dimensionless
G_{ef} = emission factor, g kg^{-1} dry matter burnt

The emission factors (G_{ef}) for methane (CH_4) and nitrous oxide (N_2O) are those in the 2006 IPCC GLs, Volume 4, Chapter 2, Table 2.5 for burning in Tropical forest.

Table 39 Variables for the estimation of Greenhouse Gas Emissions from Fire

		M_B * *Cf*	G_{ef} *CH_4*	G_{ef} *N_2O*
LU	**Sub-Category**	**Mass of fuel available for combustion * Combustion factor**	**Emission factor- CH_4**	**Emission factor- N_2O**
	Vegetation Zones	tonnes ha^{-1}	g kg^{-1} dry matter burnt	g kg^{-1} dry matter burnt
FL	Wet Evergreen	5.7	6.8	0.2
	Moist Evergreen	32.6	6.8	0.2
	Moist Semideciduous SE	45.9	6.8	0.2
	Moist Semideciduous NW	35.5	6.8	0.2
	Upland Evergreen	3.4	6.8	0.2
	Dry Semideciduous (Fire Zone)	23.4	6.8	0.2
	Dry Semideciduous (Inner)	35.2	6.8	0.2
	Savannah	36.7	6.8	0.2
	Southern Marginal	7.7	6.8	0.2

Clarification notes

MB*Cf was estimated as (AGB+Litter+DW) * fd (fire).

VIII. HISTORICAL FOREST-RELATED GHG EMISSIONS AND REMOVALS 2001-2015

Annual GHG emission and removals were estimated for the period 2001 – 2015 (Table 40). 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 estimates indicate that the average net emissions and removals are 19,659,303 tCO2e, which includes the emissions from deforestation, forest degradation and removals from enhancement of carbon stocks. It includes CO_2 emissions and removals and CH_4 and N_2O emissions from fires. Above-ground biomass, below-ground biomass, dead organic matter (litter and dead wood) and soil organic carbon pools were considered for the estimations. The methodologies of the 2006 IPCC guidelines (V2, Ch2) were followed for the calculations.

Table 40 Net historical forest related GHG emissions and removals [tCO2e]

	Year	tCO2e
Historical NET Forest related GHG emissions and removals [CO2, CH4, N2O]	2001	14,474,487
	2002	16,207,479
	2003	16,196,706
	2004	13,439,751
	2005	14,518,491
	2006	15,634,428
	2007	15,820,043
	2008	15,616,401
	2009	16,055,107
	2010	21,563,912
	2011	24,339,298
	2012	23,461,630
	2013	28,131,356
	2014	32,163,953
	2015	27,266,496

The Forest Management regime in Ghana where over a tenth of the total land area is 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 notwithstanding, over 97% of Forest land was retained during the reference period (4,089,035 ha of forest remained by 2015, compared to the initial 4,208,373 in year 2000, representing and annual loss of 0.19% and a cumulative lost of 2.88 % in 15 years) (Table 41,42)

Table 41 Total Forest Land Remaining Forest Land [Ha] (Net values)

Year	Forest	Wet Evergreen Forest	Moist Evergreen Forest	Moist Semi-deciduous SE Forest	Moist Semi-deciduous NW Forest	Upland Evergreen Forest	Dry Semi-deciduous (Fire Zone) Forest	Dry Semi-deciduous (Inner Zone) Forest	Savannah Forest	Southern Marginal Forest
2000	4,208,373	285,091	649,430	415,283	455,916	33,132	329,490	117,424	1,891,060	31,547
2001	4,208,373	285,091	649,430	415,283	455,916	33,132	329,490	117,424	1,891,060	31,547
2002	4,207,115	285,091	649,430	414,643	455,298	33,132	329,490	117,424	1,891,060	31,547
2003	4,203,464	285,091	649,430	413,363	454,680	33,132	329,490	115,672	1,889,307	31,547
2004	4,201,075	285,091	648,793	413,363	454,680	33,132	329,490	115,672	1,889,307	29,794
2005	4,191,632	280,389	648,793	413,363	453,444	33,132	329,490	115,672	1,887,555	29,794
2006	4,188,770	280,389	648,156	410,162	452,826	32,973	329,490	115,672	1,887,555	29,794
2007	4,186,455	280,389	646,901	409,522	450,973	32,654	329,490	115,672	1,889,307	29,794
2008	4,181,589	280,389	645,645	408,882	449,119	32,654	327,737	115,672	1,891,060	29,794
2009	4,171,898	280,389	645,026	408,242	447,296	32,495	327,737	115,672	1,880,544	29,794
2010	4,150,492	279,783	645,026	403,844	445,472	32,495	325,984	115,672	1,870,029	28,042
2011	4,137,576	279,783	640,623	401,283	436,355	32,177	327,737	115,672	1,868,276	28,042
2012	4,123,372	279,783	639,350	395,605	434,501	32,017	324,232	113,919	1,863,018	28,042
2013	4,114,411	277,374	633,691	392,487	430,206	31,380	322,479	115,672	1,868,276	28,042
2014	4,097,086	276,768	626,776	386,419	425,294	31,380	320,727	117,424	1,866,523	28,042
2015	4,089,035	275,555	622,337	385,779	421,616	30,902	317,221	115,672	1,873,534	26,289

Table 42 Sparklines showing trends of forest cover 2000-2015

Total Forest Land Remaining Forest Land [Ha] (Net values)	
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	

This assessment indicates that in the last 15 years, about 209,034 ha of Forest land have been cleared and converted to other land use. This represents 2.88% of forest loss in 15 years. The highest annual deforested area is 35,059 ha in 2014, where 27,203 ha of forest were converted to croplands. Empirically, this conversion is usually triggered as a result of continuous in shift agricultural activities that result in frequent clearing of the forest for new farmlands to farm. Beyond 2009, 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 43 Annual forest land converted to other land uses [Ha]

	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]
2001	0	0	0	0	0	0

2002	1258	0	0	0	0	1,258
2003	1898	1753	0	1753	0	5,403
2004	2389	0	0	1753	0	4,142
2005	4741	1753	0	2949	0	9,443
2006	3334	1280	0	0	0	4,615
2007	3131	0	0	159	777	4,068
2008	5502	0	0	0	0	5,502
2009	8977	5258	0	159	0	14,394
2010	17250	4795	0	1753	1753	25,551
2011	17238	796	0	2511	0	20,545
2012	22326	3505	0	1277	0	27,109
2013	17708	1753	0	1912	2393	23,765
2014	**27203**	4702	0	1256	1898	**35,059**
2015	21219	4430	0	1277	1256	28,181

Table 44 GHG emissions due to deforestation [tCO2]

REDD+ Activity	EMISSIONS (tCO2e)										
	Category	Sub-category	Carbon Pool	Gas	Units	Equation	2001	2002	2003	2004	2005
				CO2, CH4, N2O	**t CO2e / yr**		**0**	**837,058**	**2,291,070**	**1,223,751**	**2,247,697**
Deforestati	Forest Conversi	Forest Lands converted to other lands (AGB+BGB)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	418,639	1,067,105	616,094	971,698
		Forest Lands converted to other lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	335,907	849,734	253,279	797,531
		Forest Lands converted to other lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	82,511	374,231	354,377	478,468
		Forest lands converted to Croplands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	418,639	715,227	453,227	175,784

REDD+ Activity	Category	Sub-category	Carbon Pool	Gas	Units	Equation	2006	2007	2008	2009	2010
on	rtedtoOtherLands	Forest lands converted to Croplands (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	0	335,907	459,896	240,263	423,837
		Forest lands converted to Croplands (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	0	82,511	96,784	92,062	33,910
		Forest lands converted to Grasslands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	113,919	0	113,919
		Forest lands converted to Grasslands (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	133,193	0	133,193
		Forest lands converted to Grasslands (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	-2,827	0	-2,827
		Forest lands converted to Wetlands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	0	0	0
		Forest lands converted to Wetlands (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	0	0	0
		Forest lands converted to Wetlands (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	0	0	0
		Forest lands to Settlements (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	237,958	162,867	681,995
		Forest lands to Settlements (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	256,645	13,016	240,501
		Forest lands to Settlements (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	280,275	262,316	447,385
		Forest lands converted to Other Lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	0	0	0
		Forest lands converted to Other Lands (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	0	0	0
		Forest lands converted to Other Lands (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	0	0	0

EMISSIONS (tCO2e)

REDD+ Activity	Category	Sub-category	Carbon Pool	Gas	Units	Equation	2006	2007	2008	2009	2010
				CO2, CH4, N2O	**t CO2e / yr**		**3,314,076**	**3,092,767**	**2,973,587**	**4,244,494**	**8,828,366**
Deforestation	Forest Converted to Othe	Forest Lands converted to other lands (AGB+BGB)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	2,058,536	1,541,106	1,435,261	1,960,022	4,425,254
		Forest Lands converted to other lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	1,053,781	1,200,559	1,142,012	1,874,468	3,013,130
		Forest Lands converted to other lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	201,759	351,102	396,315	410,004	1,389,981
		Forest lands converted to Croplands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	1,394,492	1,211,007	1,435,261	1,564,487	2,871,981
		Forest lands converted to Croplands (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	805,803	758,945	1,142,012	1,360,042	1,926,479
		Forest lands converted to Croplands (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	126,481	178,721	396,315	389,327	669,792
		Forest lands converted to Grasslands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	664,044	0	0	341,758	1,307,448

	r Lands	Forest lands converted to Grasslands (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	247,978	0	0	399,578	902,487
		Forest lands converted to Grasslands (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	75,278	0	0	-8,482	185,885
		Forest lands converted to Wetlands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	0	0	0
		Forest lands converted to Wetlands (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	0	0	0
		Forest lands converted to Wetlands (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	0	0	0
		Forest lands to Settlements (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	53,778	0	53,778	100,929
		Forest lands to Settlements (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	0	114,848	0	114,848	171,148
		Forest lands to Settlements (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	0	29,158	0	29,158	271,988
		Forest lands converted to Other Lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	276,321	0	0	144,896
		Forest lands converted to Other Lands (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	0	326,766	0	0	13,016
		Forest lands converted to Other Lands (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	0	143,223	0	0	262,316

REDD+ Activity	EMISSIONS (tCO2e)										
	Category	Sub-category	Carbon Pool	Gas	Units	Equation	2011	2012	2013	2014	2015
				CO2, CH4, N2O	t CO2e / yr		**11,717,871**	**10,446,888**	**14,837,558**	**18,058,192**	**14,476,745**
Deforestation	Forest Converted to Other Lands	Forest Lands converted to other lands (AGB+BGB)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	5,671,640	5,123,409	8,497,509	10,475,577	7,422,055
		Forest Lands converted to other lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	4,983,231	3,807,744	4,592,803	5,678,006	5,130,123
		Forest Lands converted to other lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	1,063,000	1,515,735	1,747,246	1,904,608	1,924,567
		Forest lands converted to Croplands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	3,759,961	4,200,717	7,405,112	7,506,575	4,616,832
		Forest lands converted to Croplands (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	4,339,073	3,272,343	3,916,432	4,508,736	4,014,024
		Forest lands converted to Croplands (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	567,479	1,226,550	1,132,570	1,276,514	1,346,362
		Forest lands converted to Grasslands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	429,600	214,848	113,919	848,746	747,348
		Forest lands converted to Grasslands (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	221,918	304,341	133,193	498,255	673,919
		Forest lands converted to Grasslands (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	48,777	62,939	-2,827	64,733	128,587
		Forest lands converted to Wetlands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	0	0	0

Forest lands converted to Wetlands (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	0	0	0
Forest lands converted to Wetlands (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	0	0	0
Forest lands to Settlements (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	1,482,079	707,844	154,707	741,039	707,844
Forest lands to Settlements (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	422,239	231,059	285,996	211,120	231,059
Forest lands to Settlements (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	446,744	226,246	301,147	223,372	226,246
Forest lands converted to Other Lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	823,771	1,379,216	1,350,031
Forest lands converted to Other Lands (Conversion)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	257,182	459,896	211,120
Forest lands converted to Other Lands (Conversion)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	316,357	339,988	223,372

After deforestation, the extraction of biomass has a significant impact on forest land carbon stocks, as biomass harvesting is the main source of industrial round wood supply and fuelwood, which represents the key dataset for assessing the variation of carbon stocks in forestland remaining forest land. Ghana has favourable conditions for the achievement of sustainable forest management, such as impressive human resources and a long history of forest management. Nevertheless, there are many challenges such as fires that are difficult to control. Some forest reserves are well-managed, but others may have been over-harvested and off-reserve forests are often unregulated. Moreover, illegal activities such as chainsaw lumber production and poaching are thought to be widespread (ITTO, 2021[16]). Emissions from logging (legal and illegal) average 6,985,613 tCO2e, in the period 2000-2015, with minimum emissions of 5,556,104 tCO2e and a maximum of 9,962,116 tCO2e; in average, 1,774,767m3 of wood were extracted annually. Emissions from fuelwood varied between 603,944 tCO2e and 1,499,031 tCO2e, with an annual average emission of 1,126,413 tCO2e in the period 2000-2015 (Table 45).

Each year fires destroy considerable forest resources in Ghana. Studies have shown that most fires are human induced and directly linked to livelihood activities such us palmwine tapping, on-farm cooking, hunting, farming, charcoal production and cultural traditions (FORIG 2003, Agyemang et al 2015, Kalame et al 2009, Nsiah-Gyabaah 1996). For traditional farming systems, most farmers use fires as it is considered the fastest, easiest and most economic way for land preparation. Amissa et al (2010) explained that this is very common in the taungya farms (in which crops are planted together with tree seedlings on the same land until tree canopy closure) within the forest and farms outside the forest. After clearing the land, the debris is allowed to dry for some weeks. Later, fire is set to the debris for easy planting of crops. Appiah et al (2010), FORIG (2003) and Kunwar and Khaling (2006), also found that in Ghana, and other tropical countries, during hunting, fire is used to smoke out animals from holes, where the fires are started by cigarette butts dropped by smokers. In addition, farmers and hunters are also blamed because they use

[16] https://www.itto.int/sfm/2005/details/id=12330000

the fire without controlling it, turning carelessness or negligence into a common problem (Appiah el at 2010; Kunwar and Khaling, 2006).

These practices along with the flammability of a particular vegetation type make the environment susceptible to wildfires, which has resulted in negative impacts for the land such as threat to forests, changes in vegetation, invasion of certain species and weeds, soil degradation and low agricultural crop yields (Amissah et al 2011).

Table 45 Net GHG emissions and removals in forest lands affected by logging, fuelwood extraction and fires (tCO2e)

REDD+ Activity	EMISSIONS (tCO2e)										
	Category	Sub-category	Carbon Pool	Gas	Units	Equation	2001	2002	2003	2004	2005
				CO2, CH4, N2O	t CO2e / yr		16,331,543	18,057,706	18,163,857	15,096,108	16,362,666
Degradation		Forest land remaining Forest land (AGB+BGB)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.7	15,356,709	16,246,024	14,898,873	12,898,541	13,142,703
	Forest land	Forest land remaining Forest land (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Wet Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Moist Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Moist Semi-deciduous SE Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Moist Semi-deciduous NW Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Upland Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Dry Semidecidouos (Fire Zone) Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Dry Semidecidouos (Inner Zone) Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Savannah Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Southern Marginal Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Forest land remaining Forest land (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	15,356,709	16,246,024	14,898,873	12,898,541	13,142,703
		Logging	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.12	9,094,220	9,962,116	8,597,397	6,587,654	6,826,076
		Fuelwood	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.13	603,944	626,852	649,761	660,173	674,751

		Fires	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	5,658,546	5,657,056	5,651,715	5,650,713	5,641,875
		Fire_Wet Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	27,073	27,073	27,073	27,073	26,627
		Fire_Moist Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	191,655	191,655	191,655	191,467	191,467
		Fire_Moist Semi-deciduous SE Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	646,184	645,188	643,196	643,196	643,196
		Fire_Moist Semi-deciduous NW Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	363,979	363,486	362,992	362,992	362,006
		Fire_Upland Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	1,119	1,119	1,119	1,119	1,119
		Fire_Dry Semidecidouos (Fire Zone) Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	227,695	227,695	227,695	227,695	227,695
		Fire_Dry Semidecidouos (Inner Zone) Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	191,319	191,319	188,463	188,463	188,463
		Fire_Savannah Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	3,994,864	3,994,864	3,994,864	3,994,864	3,987,459
		Fire_Southern Marginal Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	14,658	14,658	14,658	13,844	13,844
		Forest land remaining Forest land (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	0	0	0
		Forest land remaining Forest land (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	0	0	0
		Forest land remaining Forest land (CH4)	Non-CO2 emissions due to biomass burning (CH4)	CH4	t CO2e / yr	Equation 2.27	679,718	679,572	679,077	679,009	677,928
		Forest land remaining Forest land (N2O)	Non-CO2 emissions due to biomass burning (N2O)	N2O	t CO2e / yr	Equation 2.27	295,116	295,052	294,837	294,808	294,339

REDD+ Activity	EMISSIONS (tCO2e)										
	Category	**Sub-category**	**Carbon Pool**	**Gas**	**Units**	**Equation**	**2006**	**2007**	**2008**	**2009**	**2010**
				CO2, CH4, N2O	**t CO2e / yr**		**17,474,897**	**17,384,454**	**17,405,916**	**17,680,295**	**23,279,601**
Degradation		Forest land remaining Forest land (AGB+BGB)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.7	13,188,631	13,319,316	13,460,641	12,466,990	13,488,288
	Forest land	Forest land remaining Forest land (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Wet Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Moist Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Moist Semi-deciduous SE Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Moist Semi-deciduous NW Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					

Upland Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
Dry Semidecidouos (Fire Zone) Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
Dry Semidecidouos (Inner Zone) Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
Savannah Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
Southern Marginal Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
Forest land remaining Forest land (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	13,188,631	13,319,316	13,460,641	12,466,990	13,488,288
Logging	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.12	6,270,983	6,414,360	6,557,929	5,556,104	6,579,784
Fuelwood	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.13	1,277,737	1,264,201	1,265,825	1,289,775	1,323,346
Fires	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	5,639,911	5,640,756	5,636,886	5,621,112	5,585,158
Fire_Wet Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	26,627	26,627	26,627	26,627	26,569
Fire_Moist Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	191,279	190,909	190,726	190,356	190,356
Fire_Moist Semi-deciduous SE Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	638,216	637,220	636,224	637,090	629,381
Fire_Moist Semi-deciduous NW Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	361,512	360,032	358,552	357,097	355,641
Fire_Upland Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	1,113	1,102	1,102	1,097	1,097
Fire_Dry Semidecidouos (Fire Zone) Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	227,695	227,695	226,484	226,484	226,484
Fire_Dry Semidecidouos (Inner Zone) Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	188,463	188,463	188,463	188,463	188,463
Fire_Savannah Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	3,991,161	3,994,864	3,994,864	3,980,054	3,954,138
Fire_Southern Marginal Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	13,844	13,844	13,844	13,844	13,029
Forest land remaining Forest land (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	0	0	0
Forest land remaining Forest land (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	0	0	0
Forest land remaining Forest land (CH4)	Non-CO2 emissions due to biomass	CH4	t CO2e / yr	Equation 2.27	677,874	678,001	677,524	675,519	671,430

			burning (CH4)								
		Forest land remaining Forest land (N2O)	Non-CO2 emissions due to biomass burning (N2O)	N2O	t CO2e / yr	Equation 2.27	294,315	294,370	294,163	293,292	291,517

REDD+ Activity	EMISSIONS (tCO2e)										
	Category	**Sub-category**	**Carbon Pool**	**Gas**	**Units**	**Equation**	**2011**	**2012**	**2013**	**2014**	**2015**
				CO2, CH4, N2O	**t CO2e / yr**		**25,611,742**	**24,687,579**	**30,223,076**	**33,059,108**	**28,223,272**
Degradation		Forest land remaining Forest land (AGB+BGB)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.7	12,931,742	13,281,194	14,425,666	14,042,662	12,784,002
	Forest land	Forest land remaining Forest land (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Wet Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Moist Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Moist Semi-deciduous SE Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Moist Semi-deciduous NW Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Upland Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Dry Semidecidouos (Fire Zone) Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Dry Semidecidouos (Inner Zone) Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Savannah Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Southern Marginal Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9					
		Forest land remaining Forest land (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	12,931,742	13,281,194	14,425,666	14,042,662	12,784,002
		Logging	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.12	5,961,102	6,311,519	7,393,195	6,989,529	5,682,222
		Fuelwood	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.13	1,391,154	1,407,315	1,467,876	1,499,031	1,494,449
		Fires	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	5,579,487	5,562,360	5,564,595	5,554,102	5,607,331

		Fire_Wet Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	26,569	26,569	26,341	26,283	26,168
		Fire_Moist Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	189,056	188,868	187,381	184,970	184,218
		Fire_Moist Semi-deciduous SE Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	624,400	615,565	612,706	605,126	601,271
		Fire_Moist Semi-deciduous NW Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	348,856	346,883	343,454	340,518	338,052
		Fire_Upland Evergreen Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	1,086	1,081	1,059	1,059	1,043
		Fire_Dry Semidecidouos (Fire Zone) Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	226,484	224,062	224,062	222,851	220,429
		Fire_Dry Semidecidouos (Inner Zone) Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	188,463	188,463	191,319	191,319	191,319
		Fire_Savannah Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	3,961,542	3,957,840	3,965,245	3,968,947	3,983,757
		Fire_Southern Marginal Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.14	13,029	13,029	13,029	13,029	61,075
		Forest land remaining Forest land (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	0	0	0
		Forest land remaining Forest land (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	0	0	0
		Forest land remaining Forest land (CH4)	Non-CO2 emissions due to biomass burning (CH4)	CH4	t CO2e / yr	Equation 2.27	670,860	669,024	669,272	668,158	671,135
		Forest land remaining Forest land (N2O)	Non-CO2 emissions due to biomass burning (N2O)	N2O	t CO2e / yr	Equation 2.27	291,270	290,473	290,580	290,097	291,389

During the period 2001 to 2015, Ghana also reported other lands converted to forest, mostly from grasslands and croplands (Table 45). This increasing trend was most notable in the later years, with a gradual increase from 2009 (Figure 26). In total, 89,695 ha of other lands were converted to forest in 15 years.

Table 46 Other Land use categories converted to Forest lands 2001-2015 [Ha]

Year	Annual Cropland Converted to Forest Land	Annual Grassland Converted to Forest Land	Annual Wetland Converted to Forest Land	Annual Settlement Converted to Forest Land	Annual Other Lands Converted to Forestland	**Total Annual conversion > F[Ha]**
2001	0	0	0	0	0	0
2002	0	0	0	0	0	0
2003	0	0	0	0	1753	1,753
2004	0	1753	0	0	0	1,753
2005	0	0	0	0	0	0
2006	1753	0	0	0	0	1,753

2007	0	1753	0	0	0	1,753
2008	637	0	0	0	0	637
2009	2950	1753	0	0	0	4,702
2010	2393	1753	0	0	0	4,145
2011	3505	4123	0	0	0	7,628
2012	4142	7010	1753	0	0	12,905
2013	9403	3505	0	1256	640	14,804
2014	5983	11134	0	0	618	17,734
2015	6015	13474	0	0	640	20,129

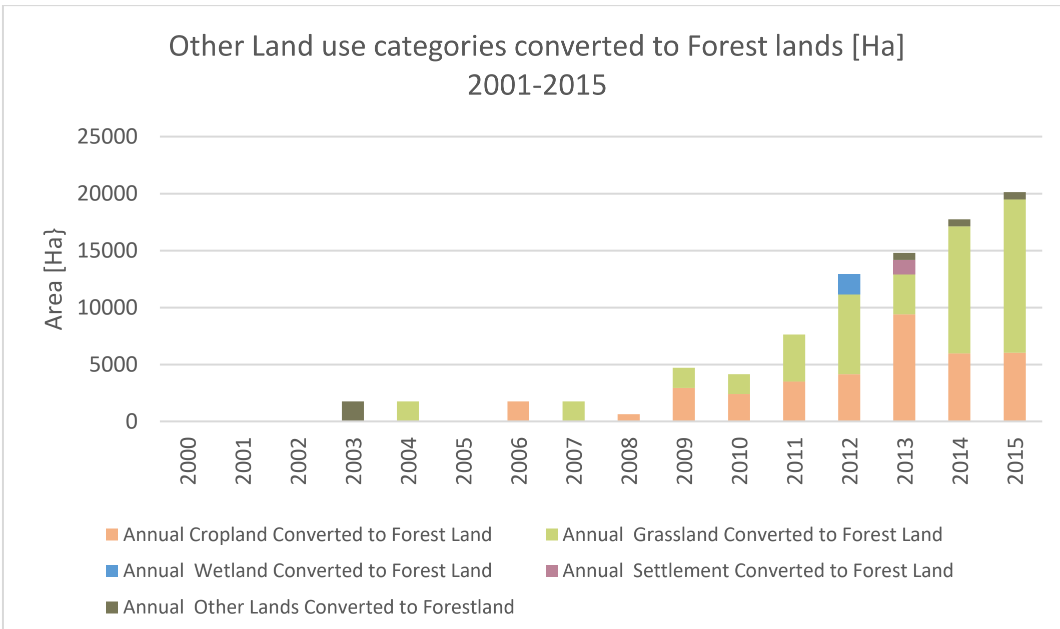


Figure 24 Other Land use categories converted to Forest lands [Ha]

Highest Removals due to enhancement of carbon stocks were achieved in 2013 with -1,159,837 tCO2e (Table 47)

Table 47 GHG removals due to enhancement of carbon stocks in lands converted to forest (tCO2e)

REDD+ Activity	GHG REMOVALS DUE TO ENHANCEMENT OF CARBON STOCKS IN LANDS CONVERTED TO FOREST (tCO2e)										
	Category	Sub-category	Carbon Pool	Gas	Units	Equation	2001	2002	2003	2004	2005
				CO2, CH4, N2O	**t CO2e / yr**		**0**	**0**	**-136,445**	**171,473**	**-34,740**
Enha	**Land**	Lands Converted to Forest Lands (AGB+BGB)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	0	0	-119,615	194,821	-11,392

ncement of Carbon Stocks	Converted to Forest Lands	Lands Converted to Forest Lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	0	0	-5,696	-11,392	-11,392
		Lands Converted to Forest Lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Lands Converted to Forest Lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	-113,919	206,213	0
		Lands Converted to Forest Lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	-6,660	-13,319	-13,319
		Lands Converted to Forest Lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	-10,170	-10,028	-10,028
		Croplands to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	0	0	0	0	0
		Croplands to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	0	0	0	0	0
		Croplands to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Croplands to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	0	0	0
		Croplands to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	0	0	0
		Croplands to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	0	0	0
		Grasslands to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	0	0	0	200,517	-5,696
		Grasslands to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	0	0	0	-5,696	-5,696
		Grasslands to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Grasslands to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	0	206,213	0
		Grasslands to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	0	-6,660	-6,660
		Grasslands to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	0	141	141
		Wetlands to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	0	0	0	0	0
		Wetlands to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	0	0	0	0	0
		Wetlands to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Wetlands to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	0	0	0
		Wetlands to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	0	0	0
		Wetlands to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	0	0	0

		Settlements to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	0	0	0	0	0
		Settlements to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	0	0	0	0	0
		Settlements to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Settlements to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	0	0	0
		Settlements to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	0	0	0
		Settlements to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	0	0	0
		Other lands to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	0	0	-119,615	-5,696	-5,696
		Other lands to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	0	0	-5,696	-5,696	-5,696
		Other lands to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Other lands to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	-113,919	0	0
		Other lands to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	-6,660	-6,660	-6,660
		Other lands to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	-10,170	-10,170	-10,170

REDD+ Activity	GHG REMOVALS DUE TO ENHANCEMENT OF CARBON STOCKS IN LANDS CONVERTED TO FOREST (tCO2e)										
	Category	Sub-category	Carbon Pool	Gas	Units	Equation	2006	2007	2008	2009	2010
				CO2, CH4, N2O	t CO2e / yr		-75,866	142,961	-129,912	-14,839	-186,123
Enhancement of Car	Land Converted to F	Lands Converted to Forest Lands (AGB+BGB)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	-41,916	183,429	-83,430	61,512	-77,751
		Lands Converted to Forest Lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	-17,088	-22,784	-41,575	-84,012	-111,356
		Lands Converted to Forest Lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Lands Converted to Forest Lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	-24,829	206,213	-41,855	145,524	33,605

bon Stocks	orest Lands	Lands Converted to Forest Lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	-19,979	-26,639	-31,992	-56,905	-78,321
		Lands Converted to Forest Lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	-13,971	-13,829	-14,490	-19,447	-30,051
		Croplands to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	-30,525	-5,696	-66,342	-121,917	-262,629
		Croplands to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	-5,696	-5,696	-24,487	-61,228	-83,525
		Croplands to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Croplands to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	-24,829	0	-41,855	-60,689	-179,104
		Croplands to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	-6,660	-6,660	-12,013	-30,266	-43,125
		Croplands to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	-3,942	-3,942	-4,603	-9,701	-17,017
		Grasslands to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	-5,696	194,821	-11,392	189,125	190,574
		Grasslands to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	-5,696	-11,392	-11,392	-17,088	-22,134
		Grasslands to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Grasslands to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	206,213	0	206,213	212,708
		Grasslands to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	-6,660	-13,319	-13,319	-19,979	-28,536
		Grasslands to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	141	283	283	424	-2,864
		Wetlands to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	0	0	0	0	0
		Wetlands to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	0	0	0	0	0
		Wetlands to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Wetlands to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	0	0	0
		Wetlands to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	0	0	0
		Wetlands to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	0	0	0
		Settlements to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	0	0	0	0	0
		Settlements to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	0	0	0	0	0
		Settlements to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Settlements to Forest	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	0	0	0

		lands (Conversion)									
		Settlements to Forest lands (DOM)	DOM	CO_2	t CO_2e / yr	Equation 2.23	0	0	0	0	0
		Settlements to Forest lands (SOC)	SOC	CO_2	t CO_2e / yr	Equation 2.24	0	0	0	0	0
		Other lands to Forest lands	Biomass (AGB+BGB)	CO_2	t CO_2e / yr	Equation 2.15	-5,696	-5,696	-5,696	-5,696	-5,696
		Other lands to Forest lands (Gains)	Biomass (AGB+BGB)	CO_2	t CO_2e / yr	Equation 2.9	-5,696	-5,696	-5,696	-5,696	-5,696
		Other lands to Forest lands (Losses)	Biomass (AGB+BGB)	CO_2	t CO_2e / yr	Equation 2.11	0	0	0	0	0
		Other lands to Forest lands (Conversion)	Biomass (AGB+BGB)	CO_2	t CO_2e / yr	Equation 2.16	0	0	0	0	0
		Other lands to Forest lands (DOM)	DOM	CO_2	t CO_2e / yr	Equation 2.23	-6,660	-6,660	-6,660	-6,660	-6,660
		Other lands to Forest lands (SOC)	SOC	CO_2	t CO_2e / yr	Equation 2.24	-10,170	-10,170	-10,170	-10,170	-10,170

REDD+ Activity	GHG REMOVALS DUE TO ENHANCEMENT OF CARBON STOCKS IN LANDS CONVERTED TO FOREST (tCO_2e)										
	Category	Sub-category	Carbon Pool	Gas	Units	Equation	2011	2012	2013	2014	2015
				CO_2, CH_4, N_2O	t CO_2e / yr		98,309	-38,557	-1,159,837	-257,163	-575,025
Enhancement of Carbon Stocks	Land Converted to Forest Lands	Lands Converted to Forest Lands (AGB+BGB)	Biomass (AGB+BGB)	CO_2	t CO_2e / yr	Equation 2.15	253,585	212,152	-784,592	234,315	75,305
		Lands Converted to Forest Lands (Gains)	Biomass (AGB+BGB)	CO_2	t CO_2e / yr	Equation 2.9	-140,306	-210,867	-326,545	-436,181	-583,638
		Lands Converted to Forest Lands (Losses)	Biomass (AGB+BGB)	CO_2	t CO_2e / yr	Equation 2.11	0	0	0	0	0
		Lands Converted to Forest Lands (Conversion)	Biomass (AGB+BGB)	CO_2	t CO_2e / yr	Equation 2.16	393,891	423,019	-458,047	670,496	658,942
		Lands Converted to Forest Lands (DOM)	DOM	CO_2	t CO_2e / yr	Equation 2.23	-115,556	-176,084	-253,727	-343,490	-464,874
		Lands Converted to Forest Lands (SOC)	SOC	CO_2	t CO_2e / yr	Equation 2.24	-39,721	-74,625	-121,518	-147,988	-185,456
		Croplands to Forest lands	Biomass (AGB+BGB)	CO_2	t CO_2e / yr	Equation 2.15	-144,575	-350,995	-509,676	-755,843	-1,008,933
		Croplands to Forest lands (Gains)	Biomass (AGB+BGB)	CO_2	t CO_2e / yr	Equation 2.9	-94,917	-125,100	-175,734	-250,724	-329,677
		Croplands to Forest lands (Losses)	Biomass (AGB+BGB)	CO_2	t CO_2e / yr	Equation 2.11	0	0	0	0	0

		Croplands to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	-49,657	-225,894	-333,942	-505,119	-679,255
		Croplands to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	-56,445	-75,117	-122,685	-161,895	-209,790
		Croplands to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	-24,902	-36,188	-66,547	-88,162	-116,937
		Grasslands to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	403,856	694,154	332,356	1,128,728	1,343,757
		Grasslands to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	-39,693	-68,678	-80,070	-108,550	-160,452
		Grasslands to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Grasslands to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	443,548	762,832	412,426	1,237,278	1,504,209
		Grasslands to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	-52,452	-80,988	-94,307	-134,265	-201,554
		Grasslands to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	-4,649	-7,928	-7,645	-6,797	-9,842
		Wetlands to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	0	-62,656	-5,696	-5,696	-5,696
		Wetlands to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	0	-5,696	-5,696	-5,696	-5,696
		Wetlands to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Wetlands to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	-56,960	0	0	0
		Wetlands to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	-6,660	-6,660	-6,660	-6,660
		Wetlands to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	-10,170	-10,170	-10,170	-10,170
		Settlements to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	0	0	-407,572	-37,052	-37,052
		Settlements to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	0	0	-37,052	-37,052	-37,052
		Settlements to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0
		Settlements to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	0	-370,520	0	0
		Settlements to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	0	0	-10,556	-10,556	-10,556
		Settlements to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	0	0	-11,169	-11,169	-11,169
		Other lands to Forest lands	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.15	-5,696	-68,352	-194,004	-95,822	-216,771
		Other lands to Forest lands (Gains)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.9	-5,696	-11,392	-27,993	-34,159	-50,760
		Other lands to Forest lands (Losses)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.11	0	0	0	0	0

		Other lands to Forest lands (Conversion)	Biomass (AGB+BGB)	CO2	t CO2e / yr	Equation 2.16	0	-56,960	-166,011	-61,663	-166,011
		Other lands to Forest lands (DOM)	DOM	CO2	t CO2e / yr	Equation 2.23	-6,660	-13,319	-19,519	-30,115	-36,314
		Other lands to Forest lands (SOC)	SOC	CO2	t CO2e / yr	Equation 2.24	-10,170	-20,339	-25,988	-31,691	-37,339

IX. FOREST REFERENCE LEVEL / FOREST REFERENCE EMISSIONS LEVEL 2016 - 2018

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 19,659,303 tCO_2e 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.

Table 48 Results historical net GHG emissions and removals 2001-2015 and FRL/FREL 2016-2019 (tCO2e)

	Year	tCO2e
Historical NET Forest related GHG emissions and removals [CO2, CH4, N2O]	2001	14,474,487
	2002	16,207,479
	2003	16,196,706
	2004	13,439,751
	2005	14,518,491
	2006	15,634,428
	2007	15,820,043
	2008	15,616,401
	2009	16,055,107
	2010	21,563,912
	2011	24,339,298
	2012	23,461,630
	2013	28,131,356
	2014	32,163,953
	2015	27,266,496
FREL/FRL [CO2, CH4, N2O]	2016	19,659,303
	2017	19,659,303
	2018	19,659,303
	2019	19,659,303

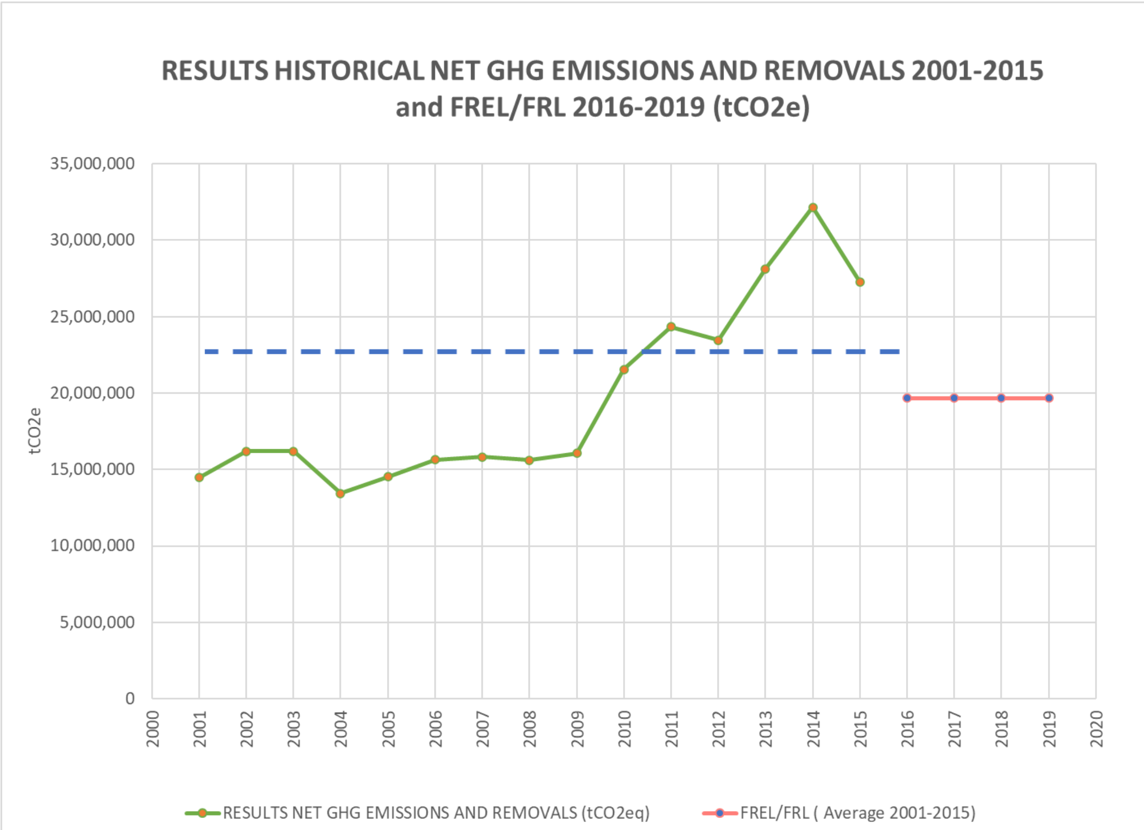


Figure 25 Results historical net GHG emissions and removals 2001-2015 and FRL/FREL 2016-2019 (tCO2e)

Historical averages were calculated based on the individual historical averages by REDD+ activity, as shown in Table 49.

Table 49 Results historical net GHG emissions and removals 2001-2015 and FRL/FREL 2016-2019 by REDD+ activities (tCO_2e)

	Year	NET National value	Forest land remaining Forest lands affected by disturbances (Degradation)	Land use categories converted to forest lands (Enhancement of C Stocks)	Forest lands converted to other land use categories (Deforestation)
Historical NET Forest related GHG emissions and removals tCO2e [CO2, CH4, N2O)	2001	14,474,487	14,474,487	0	0
	2002	16,207,479	15,370,422	0	837,058
	2003	16,196,706	14,042,081	-136,445	2,291,070
	2004	13,439,751	12,044,527	171,473	1,223,751
	2005	14,518,491	12,305,534	-34,740	2,247,697
	2006	15,634,428	12,396,218	-75,866	3,314,076

	2007	15,820,043	12,584,315	142,961	3,092,767
	2008	15,616,401	12,772,726	-129,912	2,973,587
	2009	16,055,107	11,825,452	-14,839	4,244,494
	2010	21,563,912	12,921,669	-186,123	8,828,366
	2011	24,339,298	12,523,118	98,309	11,717,871
	2012	23,461,630	13,053,300	-38,557	10,446,888
	2013	28,131,356	14,453,635	-1,159,837	14,837,558
	2014	32,163,953	14,362,924	-257,163	18,058,192
	2015	27,266,496	13,364,776	-575,025	14,476,745
FREL/FRL tCO2e [CO2, CH4, N2O)	2016	19,659,303	13,233,012	-146,384	6,572,675
	2017	19,659,303	13,233,012	-146,384	6,572,675
	2018	19,659,303	13,233,012	-146,384	6,572,675
	2019	19,659,303	13,233,012	-146,384	6,572,675

Ghana's Vision for REDD+ is to significantly reduce emissions from deforestation and forest degradation over the next twenty years. Whilst at the same time

Ghana's Vision for REDD+ is 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. By so doing, REDD+ will become a pillar of action for the national climate change agenda and a leading pathway towards sustainable, low emissions development. The main goals are:

1. Significantly reduce emissions from deforestation and forest degradation over the next twenty years, while enabling carbon stock enhancement through sustainable forest management and forest restoration strategies such as forest plantation establishment.

2. Preserve Ghana's forests in order to sustain their ecosystem services, conserve biological diversity, and maintain a cultural heritage for generations to come;

3. Transform Ghana's major agricultural commodities and NTFPs into climate-smart production systems and landscapes;

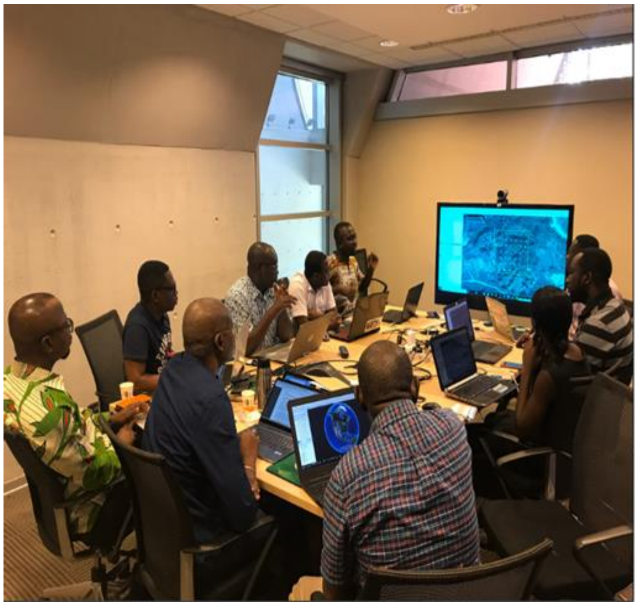
4. Expand platforms for cross-sector and public-private collaboration and sustainable economic development;

5. Generate innovative, substantial and sustainable economic and non-economic incentives and benefits to improve livelihoods across all regions of Ghana

X. 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 improving 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.



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.

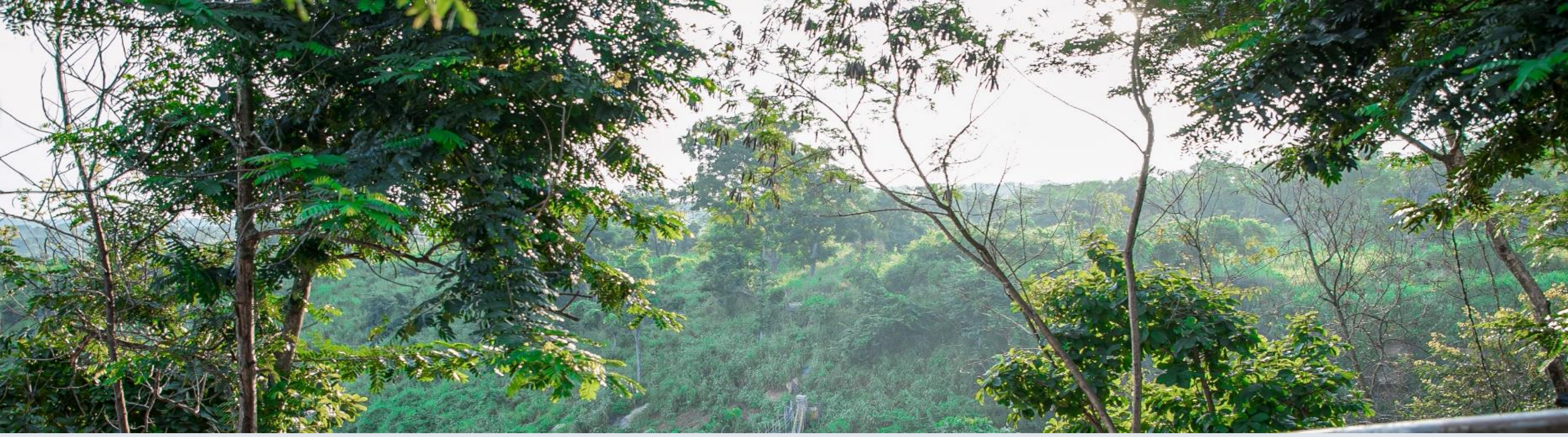
To improve the quality of the plot interpretation all sample plots that were labeled by the interpreter as "low confidence" were re-assessed and all forest or deforestation sample plots assessed in June 2019 are re-assessed since at that time the interpreters did not have access to Planet data.

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 FC 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.



XI. 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 in 1ha as consistent with the forest definition across all ecological zones in the country.

AD on Fire

Ghana intends to research into forest areas affected by fires for degradation estimates than relying on expert judgement henceforth.

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. Ghana will carry out further studies into improving in country EFs.

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.

XII. Bibliographic References

Adu-Bredu, S., Abekoe, M. K., Tachie-Obeng, E. & Tschakert P. (2010). Carbon Stock under four Land-Use Systems in Three Varied Ecological Zones in Ghana. World Soil Resources Report 104 (Africa and the Carbon Cycle). Proceedings of the Open Science Conference on "Africa and Carbon Cycle: the Carbon Africa project". Accra (Ghana) 25-27 November 2010, FAO, Rome, Italy.

Agboadoh, D. M. Y. (2011). Soil Organic Carbon Stocks in Croplands of the Bechem Forest Municipal, Ghana.MSc Thesis submitted to the Faculty of Geo-Information Scienceand Earth Observation of the University of Twente, Netherlandand the Faculty of Renewable Natural Resources of the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Agyemang, S.O., Muller, M., & Barnes, V.R. (2015). Fire in Ghana's dry forest: Causes, frequency, effects and management interventions.

Amissah, L.; Kyereh, B.; Agyeman, V. K. 2010. Wildfire incidence and management in the forest transition zone of Ghana: farmers' perspectives. Ghana J. Forestry. 26: 61-73.

Amissah, L.; Kyereh, B.; Agyeman, V. K. 2011. Wildfires as dominant force driving farming systems in the forest transition zone of Ghana. Ghana J. Forestry. 27 (2): 52-65.

Appiah, M.; Damnyag, L.; Blay, D.; Papinen, A. 2010. Forest and agroecosystem fire management in Ghana. Mitig Adapt Strateg Glob Change. 15:551-570.

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.

Bessah, E. (2014) Assessment of soil organic carbon stocks under various land use/land cover types in the Kintampo North Municipal, Ghana. Thesis submitted to the postgraduate school, Federal University of Technology, Minna, Nigeria, in partial fulfilment of the requirements for the award of the degree of Master of Technology in climate change and adapted land use.

Bessah, E.; Bala, A.; Agodzo, S. K.; Okhimamhe, A.A. (2016) Dynamics of soil organic carbon stocks in the Guinea savanna and transition agro-ecology under different land-use systems in Ghana. Cogent Geoscience (2016), http://dx.doi.org/10.1080/23312041.2016.1140319.

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.

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.

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 Researcg, volume 03, Issue:04. ISSN: 2455-6939.

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

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.

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.

Forest Research Institute of Ghana (FORIG). 2003. Final technical report: forest fire management in Ghana. Forest Research Institute of Ghana, Kumasi

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

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.

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.

Jong, Y.W. (2018) Carbon stocks in Northeastern Gabon and policy implications for rubber tree concessions. Master project submitted in partial fulfillment of the requirements for the Master of Forestry Degree in the Nicholas School of the Environment of Duke University.

Kalame, F. B.; Nkem, J.; Indinoba, M.; Kanninen, M. 2009. Matching national forest policies and management practices for climate change adaptation in Burkina Faso and Ghana. Mitig Adapt Strateg Glob Change, 14: 135-151.

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.

Kunwar, R. M.; Khaling, S. 2006. Forest Fire in the Terai, Nepal: Causes and Community management Interventions. International Forest Fire News. 34:46-54

Nsiah-Gyabaah, K. 1996. Bushfires in Ghana. International Forest Fire News. 15: 1-10.

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.

Mahamahadu, N. (2015) Carbon stock under four different land-use systems in the savanna ecosystems, in Ghana. Thesis submitted to the Department of Theoretical and applied Biology in partial fulfilment of the requiremet for the award of degree of Master of Science, 2014.

Oduro, K.A. (2016) Ghana's high forests trends, scenarios and pathways for future development. Thesis submitted in fulfilment of the requirements for the degree of doctorate, Wageningen University

Owusu, S.; Yigini, Y.; Olmedo, G.F.; Omuto, C.T. (2020) Spatial predictin of soil organic carbon stocks in Ghana using legacy data. Geoderma, vol, 360. https://doi.org/10.1016/j.geoderma.2019.114008

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.

Rhebergen, T.; Fairhurst, T.; Zingore, S.; Fisher, M.; Oberthür, T.; Whitbread, A. (2016) Climate, soil and land-use based land suitability evaluation for oil palm production in Ghana. Europ.J.Agronomy 81:1–14.

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

Saengruksawong, C.; Khamyong, S.; Anongrak, N.; Pinthong, J. (2012b) Growth and carbon stocks in rubber plantations on Chakkarat soil series, Northeastern Thailand. Suranaree J. Sci. Technol. 19(4):271-278.

Tan, Z., Tieszen, L. L., Tachie-Obeng, E., Lui, S. & Dieye, A. M. (2008). Historical and simulated ecosystem carbon dynamics in Ghana: land use, management, and climate. Biogeosciences Discuss, 5, 2343 -2368.

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.

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.

Annexes

ANNEX I. Detailed annual Land Use and Land Use Change matrices 2000-2015 [Ha]

LAND USE CHANGES

Land Use and Land Use Change (LULUC)
Vertical: Final Use
Horizontal: Initial Use

2014-2015

Land Use and Land Use Change (LULUC)	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
Wet Evergreen Forest	275,555											606	606			
Moist Evergreen Forest		622,337								1,273	1,273				637	1256
Moist Semi-deciduous SE Forest			385,779								2,477				640	
Moist Semi-deciduous NW Forest				421,616						2,441	2,472					
Upland Evergreen Forest					30,902						159		319			
Dry Semidecidouos (Fire Zone) Forest						317,221				1,753	1,753	1,753				
Dry Semidecidouos (Inner Zone) Forest							115,672						1753			
Savannah Forest								1,873,534		5,258						
Southern Marginal Forest									26,289				1753			
Croplands, Annual Crops		1892		618		1753	1753			7900656			9969		5764	
Croplands, Perennial Crops											5289448		4239	159	6814	
Croplands, Fallow												671357	5258			
Grasslands (Pasture / Savannahs / Shrublands)				1205				12268		1753		5258	4,309,907		1197	1753
Wetland														817,672		1753
Settlement										1753					612,541	
Other Lands			640													150,955
TOTAL	275,555	624,229	386,419	423,440	30,902	318,974	117,424	1,885,802	26,289	7,914,887	5,297,582	678,974	4,333,803	817,832	627,593	155,716
								20,129	4,089,035			13,891,443	4,333,803	817,832		155,716

2013-2014

Land Use and Land Use Change (LULUC)	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
Wet Evergreen Forest	276,768										606					
Moist Evergreen Forest		626,776								1,256	4,403	1,256			1256	
Moist Semi-deciduous SE Forest			386,419							1,197	3,034	640	1197			1280
Moist Semi-deciduous NW Forest				425,294						2,472	1,823					618
Upland Evergreen Forest					31,380											
Dry Semidecidouos (Fire Zone) Forest						320,727				1,753		1,753				
Dry Semidecidouos (Inner Zone) Forest							117,424									
Savannah Forest								1,866,523		5,258		1,753	3505			
Southern Marginal Forest									28,042							
Croplands, Annual Crops			1837			1753		1753		7900982			8287	1753	5908	
Croplands, Perennial Crops			640								5290153		1920		5224	
Croplands, Fallow												669462	7010			
Grasslands (Pasture / Savannahs / Shrublands)				618				10516		8847	640	1753	4,309,668		6455	1753
Wetland														817,672	1256	1753
Settlement										640					594,196	
Other Lands				618									1753			146,192
TOTAL	276,768	626,776	388,896	426,529	31,380	322,479	117,424	1,878,792	28,042	7,922,404	5,300,660	676,615	4,333,341	819,425	614,294	151,595
								17,734	4,097,086			13,899,679	4,333,341	819,425		151,595

2012-2013

Land Use and Land Use Change (LULUC)	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
Wet Evergreen Forest	277,374									1,196	1,213					
Moist Evergreen Forest		633,691								1,256	5,040					
Moist Semi-deciduous SE Forest			392,487							640	640	1,197				640
Moist Semi-deciduous NW Forest				430,206						3,059	1,236					
Upland Evergreen Forest					31,380					478					159	
Dry Semidecidouos (Fire Zone) Forest						322,479									1753	
Dry Semidecidouos (Inner Zone) Forest							115,672									
Savannah Forest								1,868,276		1,753			1753			1753
Southern Marginal Forest									28,042							
Croplands, Annual Crops			640			1753	1753	5258		7903375			6463		10911	
Croplands, Perennial Crops											5287438		1197		8665	
Croplands, Fallow												673522				
Grasslands (Pasture / Savannahs / Shrublands)								3505		8763	1753	1753	4,329,083		1753	
Wetland										1753				820,681		
Settlement		1256													571,596	
Other Lands			640								618		1753			146,169
TOTAL	277,374	634,946	393,768	430,206	31,380	324,232	117,424	1,877,039	28,042	7,922,272	5,297,937	676,472	4,340,249	820,681	594,836	148,562
								14,804	4,114,411			13,896,682	4,340,249	820,681		148,562

LAND USE CHANGES

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

2011-2012																
Wet Evergreen Forest	279,783															
Moist Evergreen Forest		639,350										637			637	
Moist Semi-deciduous SE Forest			395,605							4,398	640				640	
Moist Semi-deciduous NW Forest				434,501						1,236	1,236					
Upland Evergreen Forest					32,017					159						
Dry Semidecidouos (Fire Zone) Forest						324,232				1,753			1753			
Dry Semidecidouos (Inner Zone) Forest							113,919			1,753						
Savannah Forest								1,863,018		7,010	1,753	1,753	1753			
Southern Marginal Forest									28,042							
Croplands, Annual Crops		637						3505		7909081			3505		3505	
Croplands, Perennial Crops											5293031					
Croplands, Fallow												671133				
Grasslands (Pasture / Savannahs / Shrublands)							1753	5258		1753	640		4,337,846	3505	1205	3505
Wetland								1753		2393			1753	818,928		
Settlement															566,864	
Other Lands										618						145,675
TOTAL	279,783	639,986	395,605	434,501	32,017	324,232	115,672	1,873,534	28,042	7,930,153	5,297,300	673,522	4,346,609	822,433	572,852	149,180
								12,905	4,123,372			13,900,975	4,346,609	822,433		149,180

2010-2011																
Wet Evergreen Forest	279,783															
Moist Evergreen Forest		640,623									1,256		637		2511	
Moist Semi-deciduous SE Forest			401,283							1,920	1,280					
Moist Semi-deciduous NW Forest				436,355						618	8,499					
Upland Evergreen Forest					32,177						159		159			
Dry Semidecidouos (Fire Zone) Forest						327,737										
Dry Semidecidouos (Inner Zone) Forest							115,672									
Savannah Forest								1,868,276		1,753	1,753					
Southern Marginal Forest									28,042							
Croplands, Annual Crops								3505		7905427			5898		9595	
Croplands, Perennial Crops											5278332		1197		159	
Croplands, Fallow												671133	1753			
Grasslands (Pasture / Savannahs / Shrublands)				618				3505		8763	1753		4,344,069	1753	5371	
Wetland														823,073		
Settlement													1753		549,228	
Other Lands										1753						146,293
TOTAL	279,783	640,623	401,283	436,973	32,177	327,737	115,672	1,875,286	28,042	7,920,233	5,293,031	671,133	4,355,465	824,826	566,864	146,293
								7,628	4,137,576			13,884,397	4,355,465	824,826		146,293

2009-2010																
Wet Evergreen Forest	279,783										606					
Moist Evergreen Forest		645,026														
Moist Semi-deciduous SE Forest			403,844								3,758		1837			
Moist Semi-deciduous NW Forest				445,472							618		1205			
Upland Evergreen Forest					32,495											
Dry Semidecidouos (Fire Zone) Forest						325,984									1753	
Dry Semidecidouos (Inner Zone) Forest							115,672									
Savannah Forest								1,870,029		12,268			1753			
Southern Marginal Forest									28,042							1753
Croplands, Annual Crops			640					1753		7908651			2393		1753	1753
Croplands, Perennial Crops											5274706					
Croplands, Fallow												672886	1753			
Grasslands (Pasture / Savannahs / Shrublands)						1753				3505			4,351,633		1753	
Wetland													3505	823,073		
Settlement													1753		545,723	
Other Lands																144,540
TOTAL	279,783	645,026	404,484	445,472	32,495	327,737	115,672	1,871,781	28,042	7,924,425	5,279,688	672,886	4,365,831	823,073	550,980	148,045
								4,145	4,150,492			13,876,998	4,365,831	823,073		148,045

2008-2009																
Wet Evergreen Forest	280,389															
Moist Evergreen Forest		645,026								1,256						
Moist Semi-deciduous SE Forest			408,242							640						
Moist Semi-deciduous NW Forest				447,296							1,823					
Upland Evergreen Forest					32,495										159	
Dry Semidecidouos (Fire Zone) Forest						327,737										
Dry Semidecidouos (Inner Zone) Forest							115,672									
Savannah Forest								1,880,544		3,505		1,753	5258			
Southern Marginal Forest									29,794							
Croplands, Annual Crops								1753		7905078			3505		640	
Croplands, Perennial Crops			1197								5272243					
Croplands, Fallow												672886				
Grasslands (Pasture / Savannahs / Shrublands)								1753		5258			4,348,128		1753	
Wetland													1753	826,579		
Settlement															544,923	
Other Lands										1205	640					144,540
TOTAL	280,389	645,026	409,439	447,296	32,495	327,737	115,672	1,884,049	29,794	7,916,942	5,274,706	674,638	4,358,643	826,579	547,475	144,540
								4,702	4,171,898			13,866,286	4,358,643	826,579		144,540

2007-2008																
Wet Evergreen Forest	280,389															
Moist Evergreen Forest		645,645									1,256					
Moist Semi-deciduous SE Forest			408,882								640					
Moist Semi-deciduous NW Forest				449,119						1,854						
Upland Evergreen Forest					32,654											
Dry Semidecidouos (Fire Zone) Forest						327,737				1,753						
Dry Semidecidouos (Inner Zone) Forest							115,672									
Savannah Forest								1,891,060								
Southern Marginal Forest									29,794							
Croplands, Annual Crops										7905617					3505	
Croplands, Perennial Crops		637									5271544				618	
Croplands, Fallow												672886				
Grasslands (Pasture / Savannahs / Shrublands)										1753			4,356,891			
Wetland														828,331		
Settlement															539,047	
Other Lands															1753	146,386
TOTAL	280,389	646,282	408,882	449,119	32,654	327,737	115,672	1,891,060	29,794	7,910,976	5,273,440	672,886	4,356,891	828,331	544,923	146,386
									4,181,589			13,857,301	4,356,891	828,331		146,386

LAND USE CHANGES

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

2006-2007

	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
Wet Evergreen Forest	280,389															
Moist Evergreen Forest		646,901									1,256					
Moist Semi-deciduous SE Forest			409,522								640					
Moist Semi-deciduous NW Forest				450,973						1,236						618
Upland Evergreen Forest					32,654										159	159
Dry Semidecidouos (Fire Zone) Forest						329,490										
Dry Semidecidouos (Inner Zone) Forest							115,672									
Savannah Forest								1,889,307								
Southern Marginal Forest									29,794							
Croplands, Annual Crops										7907886						
Croplands, Perennial Crops											5270903				618	
Croplands, Fallow												672886	618			
Grasslands (Pasture / Savannahs / Shrublands)								1753					4,358,025			
Wetland														828,331		
Settlement															538,270	
Other Lands																147,361
TOTAL	280,389	646,901	409,522	450,973	32,654	329,490	115,672	1,891,060	29,794	7,909,122	5,272,799	672,886	4,358,643	828,331	539,047	148,138
									4,186,455			13,854,806	4,358,643	828,331		148,138

2005-2006

	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
Wet Evergreen Forest	280,389															
Moist Evergreen Forest		648,156									637					
Moist Semi-deciduous SE Forest			410,162							640	1,280		1280			
Moist Semi-deciduous NW Forest				452,826							618					
Upland Evergreen Forest					32,973						159					
Dry Semidecidouos (Fire Zone) Forest						329,490										
Dry Semidecidouos (Inner Zone) Forest							115,672									
Savannah Forest								1,887,555								
Southern Marginal Forest									29,794							
Croplands, Annual Crops								1753		7907246						
Croplands, Perennial Crops											5268827				1205	
Croplands, Fallow												673504				
Grasslands (Pasture / Savannahs / Shrublands)													4,358,498		1753	
Wetland														828,331		
Settlement															535,312	
Other Lands																147,361
TOTAL	280,389	648,156	410,162	452,826	32,973	329,490	115,672	1,889,307	29,794	7,907,886	5,271,521	673,504	4,359,778	828,331	538,270	147,361
								1,753	4,188,770			13,852,910	4,359,778	828,331		147,361

2004-2005

	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
Wet Evergreen Forest	280,389									1,753		1,753			1196	
Moist Evergreen Forest		648,793														
Moist Semi-deciduous SE Forest			413,363													
Moist Semi-deciduous NW Forest				453,444							1,236					
Upland Evergreen Forest					33,132											
Dry Semidecidouos (Fire Zone) Forest						329,490										
Dry Semidecidouos (Inner Zone) Forest							115,672									
Savannah Forest								1,887,555					1753		1753	
Southern Marginal Forest									29,794							
Croplands, Annual Crops										7907246			1753		1197	
Croplands, Perennial Crops											5268796					
Croplands, Fallow												671751				
Grasslands (Pasture / Savannahs / Shrublands)													4,356,745			
Wetland														828,331		
Settlement															531,166	
Other Lands																147,361
TOTAL	280,389	648,793	413,363	453,444	33,132	329,490	115,672	1,887,555	29,794	7,908,999	5,270,032	673,504	4,360,250	828,331	535,312	147,361
								0	4,191,632			13,852,534	4,360,250	828,331		147,361

2003-2004

	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
Wet Evergreen Forest	285,091															
Moist Evergreen Forest		648,793									637					
Moist Semi-deciduous SE Forest			413,363													
Moist Semi-deciduous NW Forest				454,680												
Upland Evergreen Forest					33,132											
Dry Semidecidouos (Fire Zone) Forest						329,490										
Dry Semidecidouos (Inner Zone) Forest							115,672									
Savannah Forest								1,889,307		1,753						
Southern Marginal Forest									29,794						1753	
Croplands, Annual Crops										7908443						
Croplands, Perennial Crops											5268160					
Croplands, Fallow												671751				
Grasslands (Pasture / Savannahs / Shrublands)								1753					4,356,745		1753	
Wetland														828,331		
Settlement															527,661	
Other Lands																147,361
TOTAL	285,091	648,793	413,363	454,680	33,132	329,490	115,672	1,891,060	29,794	7,910,196	5,268,796	671,751	4,356,745	828,331	531,166	147,361
								1,753	4,201,075			13,850,743	4,356,745	828,331		147,361

2002-2003

	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
Wet Evergreen Forest	285,091															
Moist Evergreen Forest		649,430														
Moist Semi-deciduous SE Forest			413,363							640	640					
Moist Semi-deciduous NW Forest				454,680							618					
Upland Evergreen Forest					33,132											
Dry Semidecidouos (Fire Zone) Forest						329,490										
Dry Semidecidouos (Inner Zone) Forest							115,672								1753	
Savannah Forest								1,889,307					1753			
Southern Marginal Forest									31,547							
Croplands, Annual Crops										7907185					1753	
Croplands, Perennial Crops											5266261					
Croplands, Fallow												671751	1753			
Grasslands (Pasture / Savannahs / Shrublands)										618	640		4,356,105		618	
Wetland														828,331		
Settlement															523,538	
Other Lands								1753					640			147,361
TOTAL	285,091	649,430	413,363	454,680	33,132	329,490	115,672	1,891,060	31,547	7,908,443	5,268,160	671,751	4,360,250	828,331	527,661	147,361
									4,203,464			13,848,354	4,360,250	828,331		147,361

LAND USE CHANGES

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

2001-2002

Wet Evergreen Forest	285,091															
Moist Evergreen Forest		649,430														
Moist Semi-deciduous SE Forest			414,643								640					
Moist Semi-deciduous NW Forest				455,298						618						
Upland Evergreen Forest					33,132											
Dry Semidecidouos (Fire Zone) Forest						329,490										
Dry Semidecidouos (Inner Zone) Forest							117,424									
Savannah Forest								1,891,060								
Southern Marginal Forest									31,547							
Croplands, Annual Crops										7906567						1753
Croplands, Perennial Crops											5265621					
Croplands, Fallow												673504				
Grasslands (Pasture / Savannahs / Shrublands)										1753			4,357,981			
Wetland														828,331		
Settlement															523,538	
Other Lands																148,001
TOTAL	285,091	649,430	414,643	455,298	33,132	329,490	117,424	1,891,060	31,547	7,908,938	5,266,261	673,504	4,357,981	828,331	523,538	149,754
									4,207,115			13,848,703	4,357,981	828,331		149,754

2000 - 2001

Wet Evergreen Forest	285,091															
Moist Evergreen Forest		649,430														
Moist Semi-deciduous SE Forest			415,283													
Moist Semi-deciduous NW Forest				455,916												
Upland Evergreen Forest					33,132											
Dry Semidecidouos (Fire Zone) Forest						329,490										
Dry Semidecidouos (Inner Zone) Forest							117,424									
Savannah Forest								1,891,060								
Southern Marginal Forest									31,547							
Croplands, Annual Crops										7906567			1753			
Croplands, Perennial Crops											5265621					
Croplands, Fallow												673504				
Grasslands (Pasture / Savannahs / Shrublands)										1753			4,357,981			
Wetland														828,331		
Settlement															523,538	
Other Lands																148,001
TOTAL	285,091	649,430	415,283	455,916	33,132	329,490	117,424	1,891,060	31,547	7,908,320	5,265,621	673,504	4,359,734	828,331	523,538	148,001
									4,208,373			13,847,444	4,359,734	828,331		148,001

2000

Wet Evergreen Forest	285,091															
Moist Evergreen Forest		649,430														
Moist Semi-deciduous SE Forest			415,283													
Moist Semi-deciduous NW Forest				455,916												
Upland Evergreen Forest					33,132											
Dry Semidecidouos (Fire Zone) Forest						329,490										
Dry Semidecidouos (Inner Zone) Forest							117,424									
Savannah Forest								1,891,060								
Southern Marginal Forest									31,547							
Croplands, Annual Crops										7908320						
Croplands, Perennial Crops											5265621					
Croplands, Fallow												673504				
Grasslands (Pasture / Savannahs / Shrublands)													4,359,734			
Wetland														828,331		
Settlement															523,538	
Other Lands																148,001
TOTAL	285,091	649,430	415,283	455,916	33,132	329,490	117,424	1,891,060	31,547	7,908,320	5,265,621	673,504	4,359,734	828,331	523,538	148,001
									4,208,373			13,847,444	4,359,734	828,331		148,001

ANNEX II Scientific literature assessed (mostly country-specific) on the average annual aboveground growth for specific types of perennial crops from Ghana.

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)[17]
Cocoa	8	2.5		CS	Isaac *et al.* (2007)[18]
Cocoa	30	2.54	15%	CS	Feuer (2013)[19]

[17] 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.

[18] 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.

[19] 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.

Cocoa	8	1.07		CS	Owusu *et al*. (2018)[20]
Cocoa	8	1.29		CS	Isaac *et al*. (2007)
Cocoa	15	1.12		CS	Isaac *et al*. (2005)[21]
Cocoa	20	1.15		CS	Asigbaase *et al*. (2020)[22]
Cocoa	3	4.3		CS	Dawoe (2009)[23]
Oil palm	7	3.1		CS	Kongsager *et al*. (2013)
Oil palm	16	1.8		CS	Kongsager *et al*. (2013)
Oil palm	23	2.0		CS	Kongsager *et al*. (2013)
Oil palm	25	1.0 – 2.5			Germer and Sauerborn, 2008)[24]
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)[25]
Rubber	14	5.45		CS	Wauters *et al.* (2007)[26]
Rubber	23	4.7 - 5.1			Yang et al. (2005)[27]
Rubber		3.5			Saengruksawong *et al*.(2012)[28]
Rubber	30	0.48			Norgrove and Hauser (2013)[29]
Rubber	20	4.63	10%	CS	Feuer (2013)
Orange	25	3.1		CS	Kongsager *et al*. (2013)

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20 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.

21 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

22 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.

23 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.

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

25 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.

26 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

27 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

28 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.

29 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.

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)[30]
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)[31]

Clarification Note:

- Most of the values provided are not accompanied by an error range.
- Some publications 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.

ANNEX III Scientific literature assessed (mostly country-specific) on the above-ground biomass for specific types of perennial crops from Ghana.

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)

30 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.

31 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.

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)