Ethiopia's Forest Reference Emission Level and Forest Reference Level Submission to the UNFCCC

January 2026

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Acronyms

AD	Activity Data
AGB	Above ground biomass
ART	Architecture for REDD+ Transactions
BGB	Below ground biomass
BTR	Biennial Transparency Report
CEO	Collect Earth Online
CDM	Clean Development Mechanism
CGIAR	Consultative Group on International Agriculture Research
CP	Conference of Parties
COP	Conference of Parties
CSA	Central Statistics Authority
EF	Emission Factor
FAO	Food and Agriculture Organization of the United Nations
FREL	Forest Reference Level
FRL	Forest Reference Level
GFRA	Global Forest Resources Assessment
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
LULC	land use/land cover
NAMAs	Nationally Appropriate Mitigation Actions
MAI	Mean Annual Increment
MMU	Minimum mapping unit
MRV	Measurement, Reporting, and Verification
NDC	Nationally Determined Contribution
NFI	National forest invention
QAQC	Quality Assurance and Quality Control
REDD	Reducing emissions from deforestation and forest degradation
RS	Remote sensing
SEPAL	System for Earth Observation Data Access, Processing, and Analysis for Land Monitoring
SOC	Soil Organic Carbon
SOPs	Standard Operating Procedures
SRTM	Shuttle Radar Topographic Mission
SU	Sampling unit
tCO2 e	Ton of carbon dioxide equivalent
TREES	The REDD+ Environmental Excellence Standard
UNFCCC	United Nations Framework for Conventions on Climate Change

Summary: Ethiopia's Forest Reference Emission Level (FREL) and Forest Reference Level (FRL)

Ethiopia's FREL and FRL have been developed in the context of accessing results-based payments for REDD+ implementation. The FRL encompasses deforestation, afforestation, aboveground biomass (AGB), belowground biomass (BGB), deadwood, litter, soil organic carbon, and associated CO_2 emissions. It is defined at the national level and based on the historical average of emissions and removals observed between 2013 and 2017.

- Forest Reference Emission Level (deforestation and forest degradation): **27,284,780** t CO_2e per year
- Forest Reference Level (removals reference level): **−1,031,504** t CO_2e per year

The selected construction approach and historical reference period are provisional and may be revised in the future, subject to comprehensive assessments and evolving national circumstances.

1.Introduction

Ethiopia is pleased to accept the invitation to voluntarily submit its Forest Reference Emission Level (FREL) and Forest Reference Level (FRL), as outlined in Decision 12/CP.17, paragraph 13. This submission is made within the framework of results-based payments for activities aimed at reducing emissions from deforestation and forest degradation, while also recognizing the critical roles of conservation, sustainable forest management, and the enhancement of forest carbon stocks (REDD+) under the United Nations Framework Convention on Climate Change (UNFCCC).

Ethiopia reaffirms its commitment to advancing transparent, credible, and internationally consistent forest sector reporting. In addition to its obligations under the United Nations Framework Convention on Climate Change (UNFCCC), Ethiopia intends to submit TREES documentation to the Architecture for REDD+ Transactions (ART) Secretariat. This dual engagement underscores Ethiopia's determination to ensure coherence across international frameworks governing REDD+ implementation and results-based payments.

Accordingly, Ethiopia's Forest Reference Emission Level/Forest Reference Level (FREL/FRL) submission to the UNFCCC in 2026 has been prepared to guarantee consistency in international reporting. The submission is designed to align with decisions of the UNFCCC Conference of Parties (COP), including the Paris Agreement ((“Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 11 December 2015. Addendum. Part two: Action taken by the Conference of the Parties at its twenty-first session,” n.d.)) and the Warsaw Framework for REDD+, while also meeting the methodological and procedural requirements of ART TREES. By harmonizing these frameworks, Ethiopia seeks to strengthen the credibility of its Measurement, Reporting, and

Verification (MRV) system, enhance access to international climate finance, and contribute to global efforts to mitigate climate change through sustainable forest management.

In preparing this submission, Ethiopia has adhered to the guidance provided by the UNFCCC through decisions adopted by the Conference of the Parties (CP). Specifically, the modalities for FREL and FRL set forth in Decision 12/CP.17, together with the guidelines for reference level submissions contained in its Annex, have been followed. Ethiopia's initial FRL submission was presented in December 2015. This revised version incorporates updates that were anticipated in the original submission—such as national-level emission factors derived from the recently completed National Forest Inventory (NFI)—as well as clarifications arising from the technical assessment process conducted over the past eight months. Importantly, this submission does not alter or prejudge Ethiopia's Nationally Determined Contributions (NDCs) or Nationally Appropriate Mitigation Actions (NAMAs) under the Bali Action Plan.

Ethiopia is committed to a step-wise approach in the development of its national FREL and FRL, consistent with the guidance provided in Decision 12/CP.17, paragraph 10. Accordingly, the current FREL and FRL reflects the best information available at the time of submission. Its scope and methodologies may be refined as improved data becomes accessible, and adjustments to the historical period considered or the construction approach may be undertaken in future iterations.

2. Scale

The updated Forest Reference Emission Level (FREL) and Forest Reference Level (FRL) encompass the entire national territory of Ethiopia (113,528,063 ha).

3. Scope: Activities, Pools and Gases Included

3.1. Redd+ Activities included in the FRL

This FREL and FRL includes the REDD+ activities deforestation (forest loss), forest degradation and forest gain (enhancement of forest carbon stocks).

Deforestation (forest loss): is defined as a direct, human-induced, long-term or permanent conversion of forest land to another land use or land cover at a scale of the minimum mapping unit (MMU) of the forest definition of Ethiopia (0.5 ha) or the long-term reduction of tree canopy cover below the 20% threshold set in the Ethiopia's forest definition.

Forest degradation is defined as a direct, human-induced, long-term loss (persisting for at least 5 years) of at least 10% of forest carbon stocks, likely to be characterized by a reduction of tree canopy cover of at least 10% that does not fall below the 20% threshold that qualifies as deforestation and/or a reduction of forest biodiversity since the beginning of the measurement period on a forest land at a scale of the minimum mapping unit (MMU) of the forest definition of Ethiopia (0.5 ha) thereby lower the capacity of the forest to supply products and/or services in forest land remaining forest land.

Enhancement of forest carbon stocks through forest gain is defined as a direct, human-induced or natural, permanent conversion of non-forest land classes to forest land at a scale of the minimum mapping unit (MMU) of the forest definition of Ethiopia (0.5 ha) in a given period of time. Under the current submission, forest gain is limited to land that has been non-forest for a period of at least five years prior to the start of planting or restoration activities.

Forest gain is further disaggregated into two sub-activities:

- **Natural forest restoration** is defined as tree planting or natural regeneration with the intention of restoring natural forest cover, without a commercial purpose. It includes restoration of degraded shrubs and woodlands resulting in a transition above the thresholds in the forest definition. It also includes afforestation/reforestation (AR) and assisted natural regeneration (ANR).
- **Commercial forest planting:** is defined as any homogeneous tree planting or forest regeneration with commercial purposes.

Excluded REDD+ activities

Enhancement of forest carbon stock in forest land remaining forest land (or the opposite of forest degradation) is not accounted for in the current submission. Ethiopia intends to submit a TREES Registration Document to ART-TREES and seeks to align both submissions to enhance transparency. As ART-TREES currently does not allow the inclusion of removals on forest land remaining forest land, Ethiopia decided to also leave this out of the scope of the UNFCCC submission at least for now. Ethiopia's forests are an important carbon sink. Ethiopia considers reporting on any emissions on standing forest through forest degradation but not reporting on removals from standing forest not affected by degradation to be conservative.

Conservation of forest carbon stocks and sustainable management of forests are not defined or used as activities in Ethiopia's FREL/FRL. The carbon fluxes associated with these activities are however fully covered by Ethiopia's definition of enhancement of forest carbon stocks (both forest gain and removals in forest remaining forest). We do not expect these activities to be associated with emissions but if these would happen, they would be fully covered through the activities deforestation and forest degradation.

3.2. Carbon Pools In the FREL and FRL

The Forest Reference Level (FRL) encompasses the following carbon pools: aboveground biomass (AGB), belowground biomass (BGB), deadwood (DW), litter, and soil organic carbon (SOC). Primary data for AGB, BGB, and DW was systematically collected through Ethiopia's National Forest Inventory (NFI) during the period 2014–2016 (MEFCC, 2018). Between 2014 and 2016, comprehensive ground inventory data has been systematically collected through Ethiopia's National Forest Inventory. In parallel, both wall-to-wall and sample-based remote sensing assessments have been conducted at the national scale. Accordingly, this submission is based on nationally derived activity data, emission factors, and forest growth rates, including the Mean Annual Increment (MAI). Litter and soil organic carbon (SOC) are estimated by Litter carbon and SOC are obtained from a study entitled "*Evaluation of the forest carbon content in soil and litter in Ethiopia, Implementing agency: Natural Resources Institute Finland (LUKE) and Ethiopia Environment and Forestry Research Institute (EEFRI) Duration of the Report: August 2017 - February 2018. APPENDIX 2. Tables of basic statistics of Stoniness, SOC and Litter in the 98 SUs. (page 4)"* (*MEFCC, 2018*).

3.3. Gases in the FREL and FRL

The proposed FREL and FRL consider only CO_2 emissions. As noted in Ethiopia's submission to the UNFCCC in 2017 (UNREDD, 2017), non-CO_2 emissions are expected from burned areas. However, because Ethiopia does not systematically collect data on fire occurrence, the available information is not considered sufficiently reliable for inclusion in the FRL. For reference, Ethiopia reported burned forest areas of 200 ha in 2003, 800 ha in 2006, and 100 ha in 2008 to FAO's Global Forest Resources Assessment (FRA) in 2015 (FAO, 2016).

To assess the potential significance of non-CO_2 gases, an indicative calculation was undertaken. Annual non-CO_2 emissions were estimated for two scenarios: (i) a burned area of 100 ha in the lowest biomass forest type (biome 1), and (ii) a burned area of 800 ha in the highest biomass forest type (biome 4). Emissions were calculated using Equation 2.27 of the 2006 IPCC Guidelines, applying default emission factors from Table 2.5 (Tropical Forest) and combustion factors from Table 2.6 (Secondary Forest) (Eggleston et al., 2006).

The results suggest that non-CO_2 emissions contribute between 0.1 and 37,000 t CO_2 eq for CO, 0.1 and 33,000 t CO_2 eq for CH_4, and 3,000 to 11,000 t CO_2 eq for N_2O. Overall, the contribution of non-CO_2 gases is estimated to be less than 2% of total annual emissions from forest land in Ethiopia.

4. Forest Definition

Ethiopia adopted a forest definition as follows: land spanning at least 0.5 ha covered by trees (including bamboo) (with a minimum width of 20m) attaining a height of at least 2m and a canopy cover of at least 20% or trees with the potential to reach these thresholds in situ in due course and excluding land that is predominantly under agricultural or urban land use.

The forest definition adopted for this submission is the same as that adopted in February 2015 and used in the previous FREL/FRL (2016) submission.

However, it differs from the one applied in international reporting to the Global Forest Resources Assessment (GFRA), which follows the FAO thresholds of 10% canopy cover, a minimum area of 0.5 hectares, and a tree height of 5 meters.

Ethiopia has revised its national forest definition to more accurately reflect the natural primary state of the country’s forest vegetation. In particular, the threshold for tree height has been lowered from 5 meters to 2 meters in order to capture vegetation types such as dryland forests, where trees typically reach heights of 2–3 meters. This adjustment allows for the inclusion of areas previously classified as dense woodlands, which are widely distributed across the country. Given that commercial agriculture is expanding primarily in these dense woodland areas, Ethiopia seeks to ensure that their conservation can benefit from REDD+ incentives.

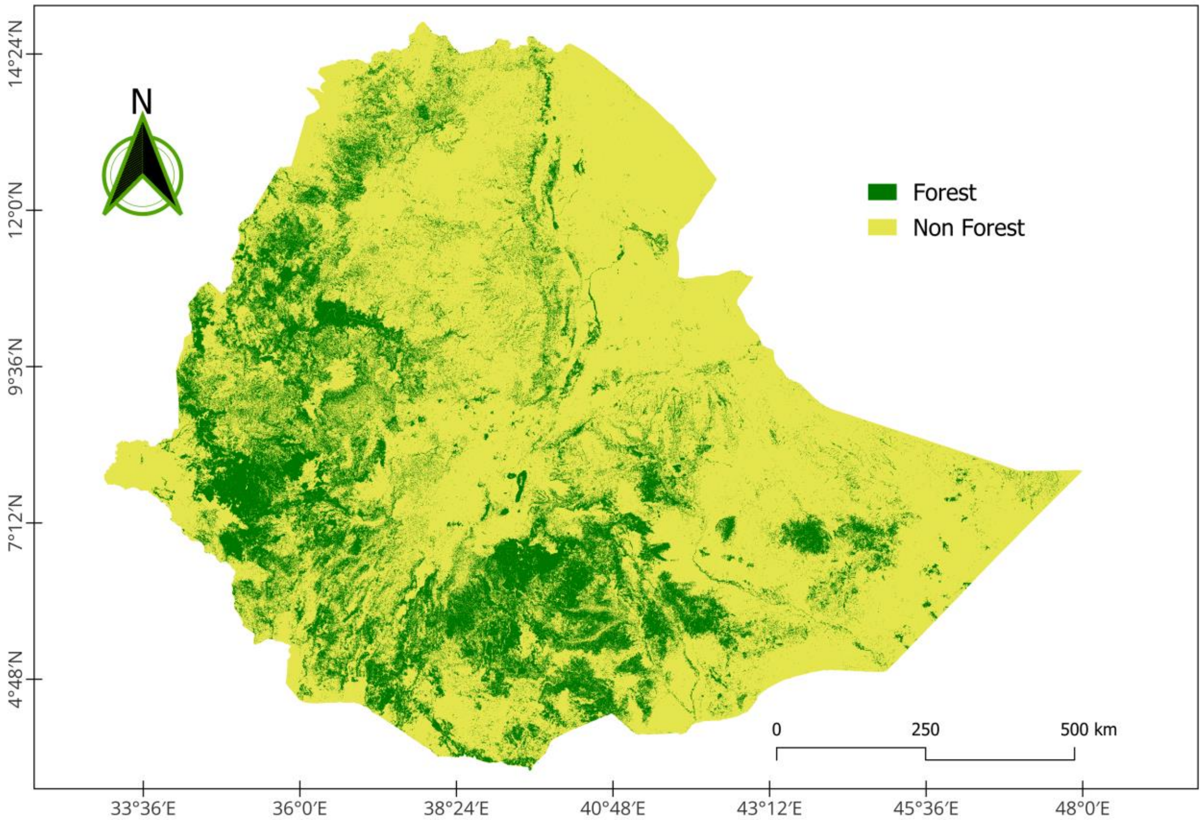

Figure 1: Forest cover map of Ethiopia for the year 2017

The canopy cover threshold has been increased from 10% to 20% in order to prevent the inclusion of highly degraded forest lands within the national forest definition. This adjustment ensures that the definition provides stronger incentives for the conservation and protection of higher-quality forest resources.

The revised forest definition also differs from the one previously applied under the Clean Development Mechanism (CDM) framework, as submitted to the UNFCCC. The CDM definition specifies: "A minimum of 0.05 ha of land covered by trees attaining a height of more than 2 m and a canopy cover of more than 20%.” The key distinction lies in the increased minimum area threshold adopted for the FRL. This change reflects the technological limitations currently faced in measuring and monitoring forest changes at very small spatial scales.

With improvements in data quality for forest area change assessments and the adoption of the revised forest definition, Ethiopia will apply these updates in future greenhouse gas (GHG) inventory reporting. Specifically, the Biennial Transparency Report (BTR) will incorporate the improved datasets and new definition.

5. Drivers Of Deforestation and Forest Degradation

In 2015, Ethiopia's REDD+ Secretariat published a comprehensive study examining the key drivers of deforestation and forest degradation across the country. The analysis highlighted that the primary pressures stem from free livestock grazing, fodder use, and fuelwood collection (including charcoal production) across all regions. These were followed by farmland expansion, land fires, and the harvesting of construction wood.

Underlying causes, identified through a framework analysis, include rapid population growth, insecure land tenure, and weak law enforcement mechanisms. Free grazing was found to exert the greatest impact on plains and lowland woodlands. In addition, large-scale agricultural investment schemes (both private and state-owned) have played a significant role in driving forest loss in Gambella, Benishangul-Gumuz, and Afar Regional States. In Ethiopian Somali and Afar Regional States, charcoal production is widespread, with nearly all rural households relying on it as a core source of livelihood income.

The risk of emissions being displaced from deforestation to forest degradation is considered minimal and considering both activities are included in the FREL the associated emissions would be fully covered. While deforestation is primarily driven by the expansion of agricultural land, degradation is largely associated with fuelwood and charcoal collection, livestock grazing, harvesting of construction materials, and illegal logging. Although certain drivers—such as grazing and wood collection—may overlap and, over time, contribute to the conversion of forests into open woodlands, addressing these pressures is expected to yield positive outcomes for both deforestation and forest degradation.

These findings are further corroborated by land-use change assessments conducted through Ethiopia's National Forest Monitoring System, which compared maps of forest areas replaced following deforestation (Figure 2).

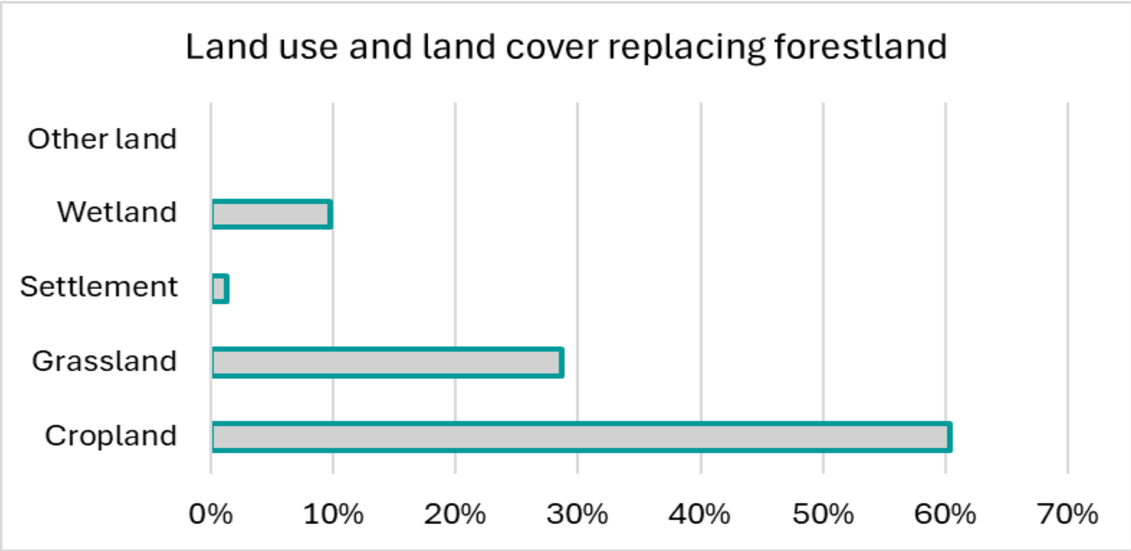

Figure 2: Land-uses replacing forest over the period 2013-2017 (as % of the total forest loss over this period)

6. Historical Period

The forest area change assessment was conducted for the five-year historical period 2013–2017. This timeframe was chosen as the reference period because:

- Ethiopia's National Forest Monitoring System (NFMS) had reliable satellite imagery and land-use data for this period, ensuring consistency in forest area change assessment.
- The years 2013–2017 coincide with Ethiopia's REDD+ readiness phase, during which methodologies, institutional arrangements, and capacity for Measuring, Reporting, and Verification (MRV) were established. Using this period demonstrates progress and readiness.
- International guidelines recommend using a recent, continuous, and representative historical period to establish FRELs. 2013–2017 provides a five-year span that balances recency with sufficient length to capture trends.
- Ethiopia's REDD+ Secretariat had completed major analytical studies (e.g., drivers of deforestation and forest degradation in 2015) and were able to integrate those findings into the FREL submission.
- The Green Climate Fund requires credible baselines for performance-based payments. A recent, verifiable period like 2013–2017 strengthens Ethiopia's case for results-based finance.
- The previous FREL/FRL (2017) proposed by Ethiopia covered the historical reference period 2000–2013 and that the updated FREL/FRL (2026) builds on this by continuing from 2013 onwards
- Ethiopia also intends to submit a TREES registration document to the ART (Architecture for REDD+ Transactions) Secretariat based on the same historical period 2013-2017. This ensures consistency between reporting under the UNFCCC Warsaw Framework for REDD+ and ART TREES.

7. The Ethiopian Biomes

A potential vegetation map of Ethiopia was developed by Friis and Sebsebe (2009), and later refined by Friis, Demissew, and van Breugel (2010) (Friis and Demissew, 2009). The map classifies Ethiopia's vegetation into 14 major types (Figure 3), which are further grouped into four overarching biomes.

The classification draws upon previous literature, the extensive field experience of the authors, and a detailed analysis of approximately 1,300 woody plant species from the flora of Ethiopia and Eritrea. The mapping process was informed by broad field surveys conducted primarily along national roads, combined with a set of criteria defining the altitudinal and rainfall thresholds for each vegetation type.

Supporting datasets included a 90 × 90-meter resolution digital elevation model provided by CGIAR-CSI (2008) for altitude, and monthly rainfall data at 30 arc-second resolution from WorldClim. Wetlands and lakes were delineated using the Global Lakes and Wetlands Database (GLWD), while the AEON river database (average stream separation of 15 km) was employed to define water bodies and associated vegetation boundaries.

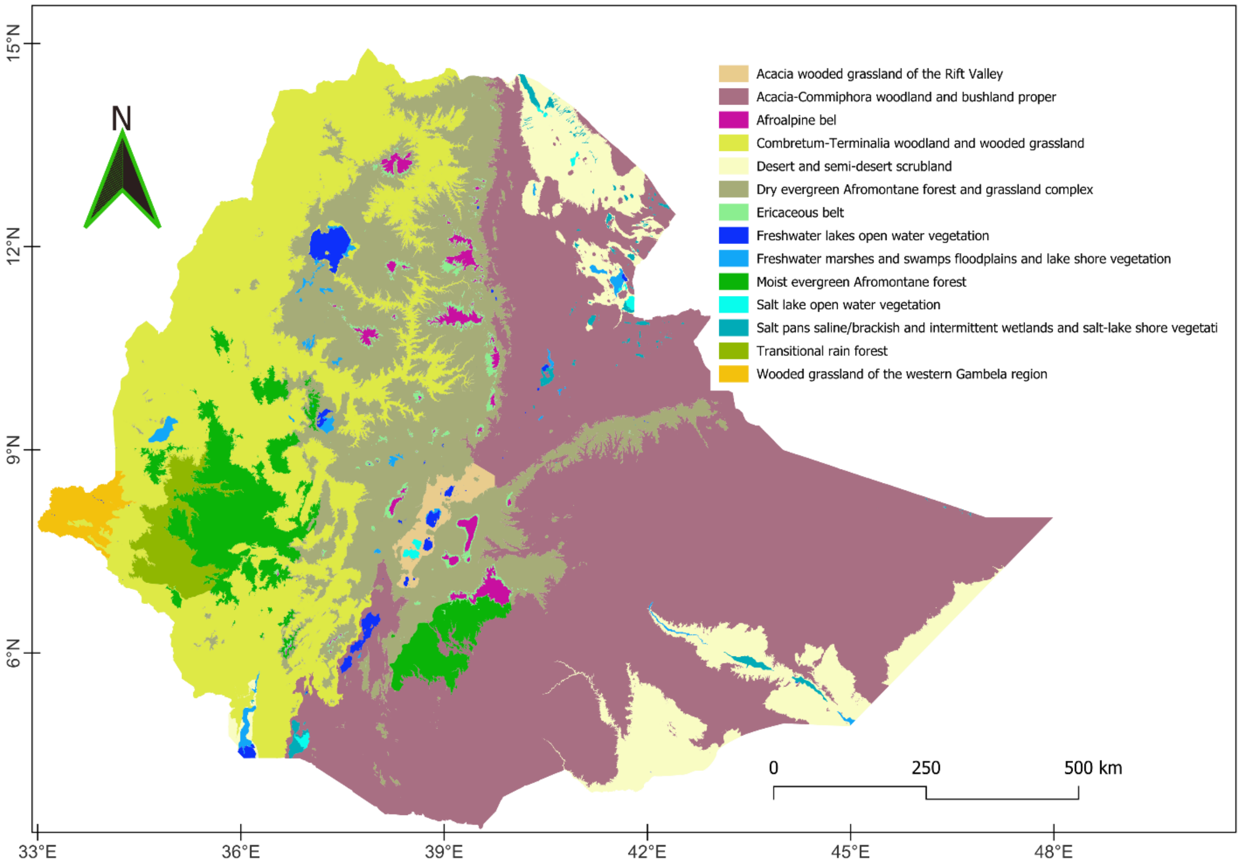

Figure 3: Potential vegetation map of Ethiopia

The potential vegetation map was also utilized as a key input in developing the strata map, which serves as the foundational layer for designing Ethiopia's National Forest and Landscape Inventory.

Since the Inventory encompasses more than just forest strata, a new aggregation map was introduced in 2015 to enhance the reliability of carbon stock estimates. Drawing on the 14 vegetation types identified in the potential vegetation map, Ethiopian botanical experts applied their knowledge of vegetation characteristics and physiology to consolidate these into four biomes. This aggregation was intended to reflect biomes with relatively homogeneous carbon content, thereby improving the accuracy of national carbon assessments (Figure 4). This revised stratification has been applied to support the estimation of carbon content for Forest Reference Level (FRL) purposes.

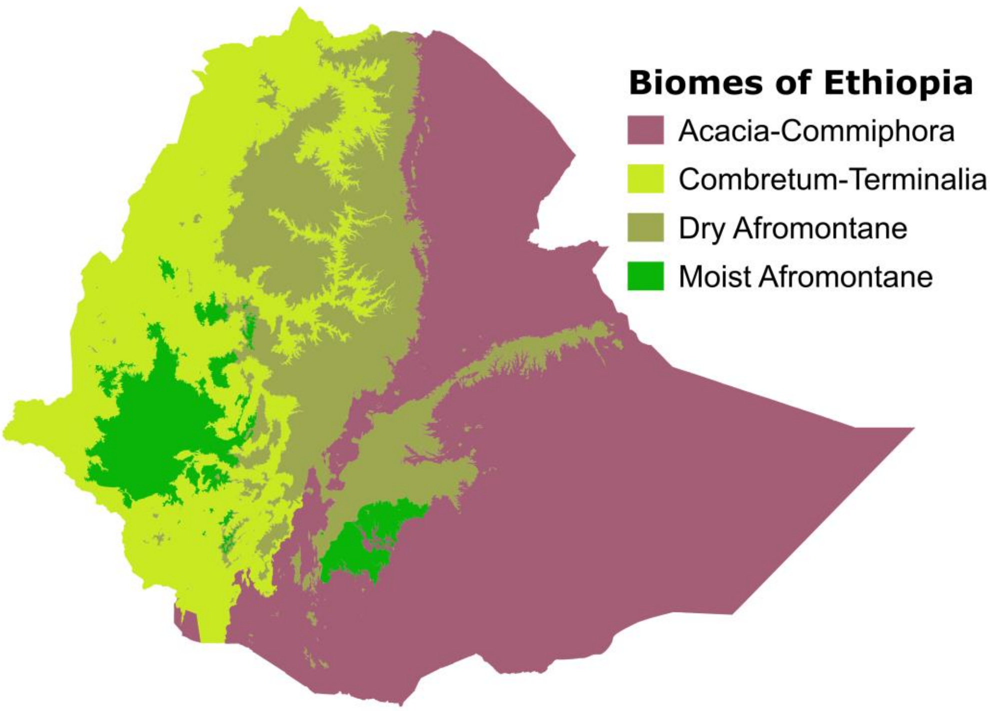

Figure 4: Biomes of Ethiopia

Table 1: Biomes description

#	Biome	Vegetation types (*Friis and Sebsebe 2009*)	Area (in ha)
1	*Acacia-Commiphora*	• *Acacia-Commiphora* woodland and bushland (ACB); • Acacia wooded grassland (ACB/RV); • Desert and semi-desert scrubland (DSS)	*52,903,764*
2	*Combretum-Terminalia*	• *Combretum-Terminalia* woodland and wooded grassland (CTW); • Wooded grassland of the Western Gambela region (WGG)	*27,232,602*
3	Dry Afromontane	• Dry evergreen Afro-Montane Forest and Grassland complex (DAF) • Afro-Alpine vegetation (AA); • Ericaceous Belt (EB);	24,254,759
4	Moist Afromontane	• Moist Evergreen Afro-Montane Forest (MAF); • Transitional Rain Forest (TRF)	9,136,937
	Total		**113,528,063**

8. The Activity Data Assessment Process

Activity data for deforestation and afforestation is calculated as an annual forest loss and forest gain, expressed in hectares, following a forest cover change detection over the period 2013–2017.

8.1. Satellite data acquisition

The Ethiopian FREL and FRL assessments considered two primary categories of land use change:

- Forest gain: conversion of non-forest land to forest
- Forest loss: conversion of forest land to non-forest uses

To ensure accuracy, forest area change was corrected for bias using a stratified random sample approach. This involved visual interpretation of high-temporal and high-spatial resolution satellite imagery where available. Landsat data, adapted for forest cover detection (FAO & JRC, 2012), was selected as the primary source. Two mosaics—representing the years 2013 and 2017—were analyzed to quantify changes during this period.

For the forest cover change analysis, Landsat 8 imagery was acquired for 2013 and 2017, covering the entire boundary of Ethiopia. The images were downloaded and mosaicked using the System for Earth Observation Data Access, Processing, and Analysis for Land Monitoring (SEPAL) platform. To minimize cloud interference, imagery was selected from the relatively clear period of December to January (Figure 5).

SEPAL is a web-based cloud-computing platform developed by the Food and Agriculture Organization of the United Nations (FAO) to support remote sensing and satellite-based forest monitoring in developing countries. It enables users to generate image composites, process satellite data, design stratified sampling frameworks, and perform related analyses directly through a browser interface (Figure 6).

Accordingly, Landsat 8 optical mosaics were created for the periods 01 December 2012 – 31 January 2013 and 01 December 2016 – 31 January 2017, representing the baseline years 2013 and 2017 (Figure 5).

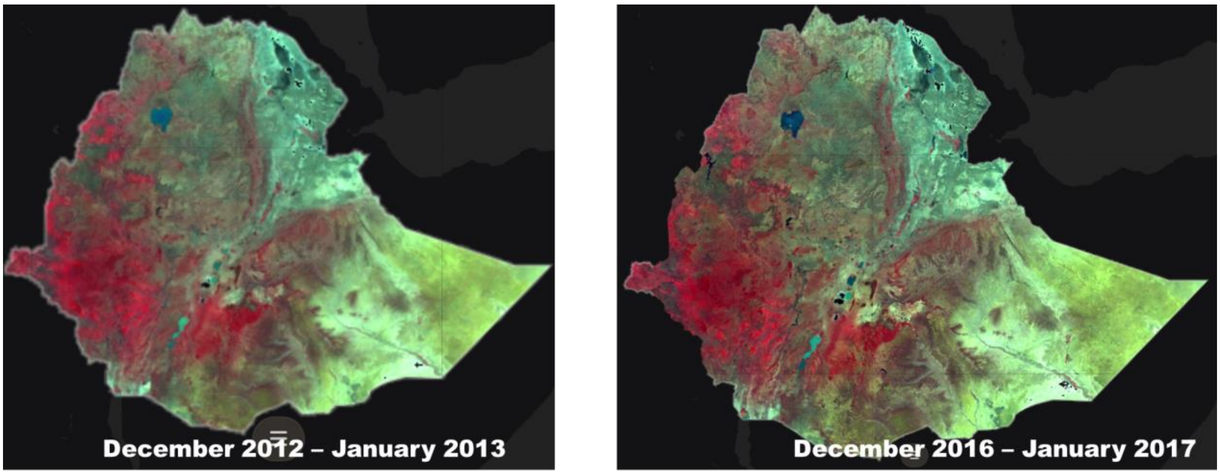

Figure 5: Landsat 8 optical mosaics ready for analysis for 2013 and 2017

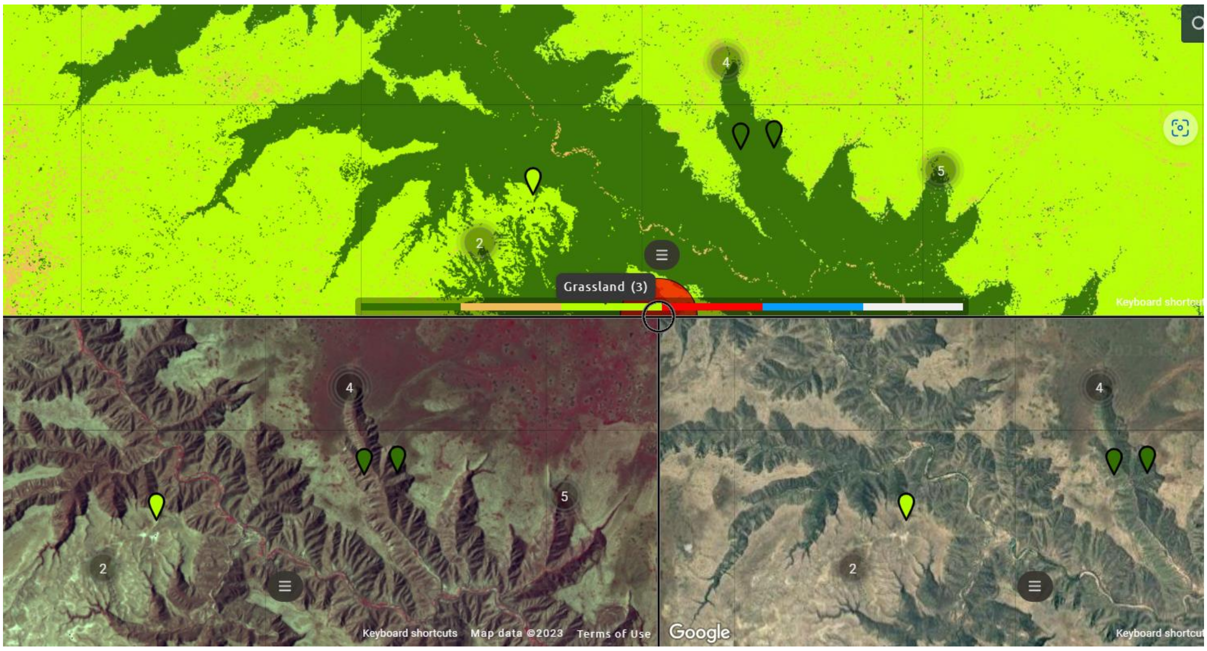

Figure 6: SEPAL interface

The forest mapping activity was carried out by dividing the country into distinct Areas of Interest (AOIs). Each AOI was further stratified into 10 classes, following the vegetation classification of Friis and Demissew (2010) and the agro-ecological zones (AEZ) of Ethiopia (Figure 7). Within these subdivisions, homogeneity was achieved in terms of topography (elevation) and key climatic parameters such as rainfall and temperature.

This stratification enabled more precise classification of land features according to vegetation types, thereby enhancing the overall accuracy of the Land Use and Land Cover (LULC) maps.

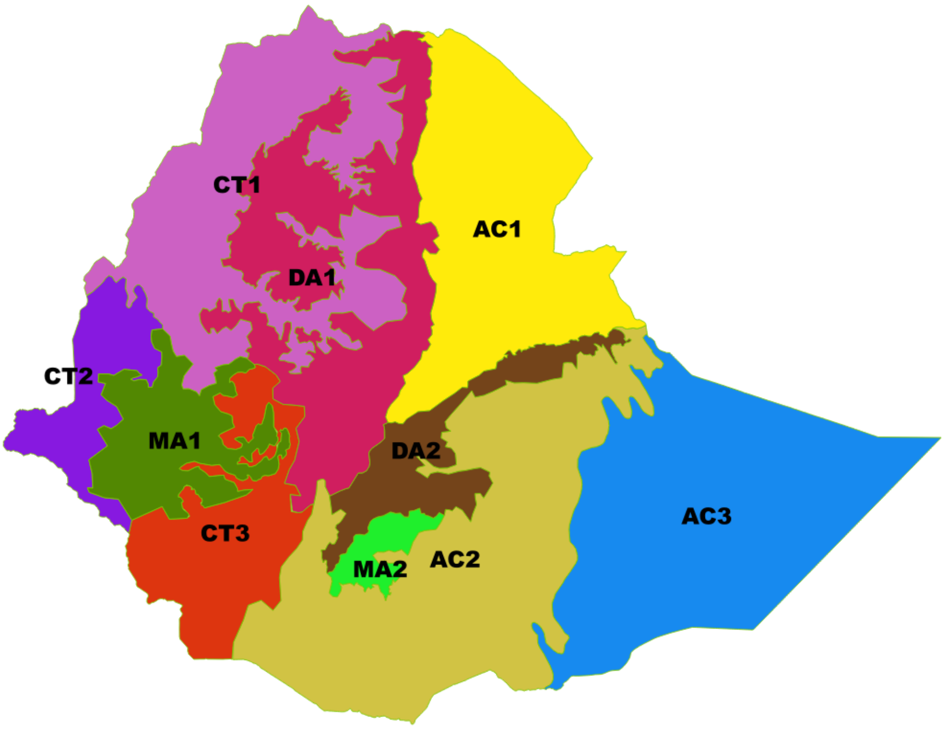

Figure 7: Subdivision of the AOI

AC = *Acacia-Commiphora*; CT = *Combretum-Terminalia*; DA = Dry Afromontane; MA = Moist Afromontane

8.2. Training Data Collection

Supervised classification relies heavily on the quality of the training sites (Foody and Mathur, 2006). To ensure accuracy, points representing forest loss and gain were rigorously evaluated through visual interpretation of Landsat time-series imagery, vegetation indices, and very high-resolution imagery available from Google Earth, and Bing Maps. Using SEPAL's built-in training data collection tool training data points were collected for both change and stable classes to support image-to-image change detection. Training data collection in SEPAL is an iterative process until satisfactory classification is reached for each class. These were derived through visual interpretation of Very High Resolution (VHR) imagery from Google Earth, using SEPAL, and cover the entire country. Change points were carefully validated through visual interpretation of vegetation indices, and very high-resolution imagery available in Google Earth. The dataset was employed to train the random forest classification algorithm. Illustrative demonstrations of training points for each class in SEPAL are presented (Figures 8–10).

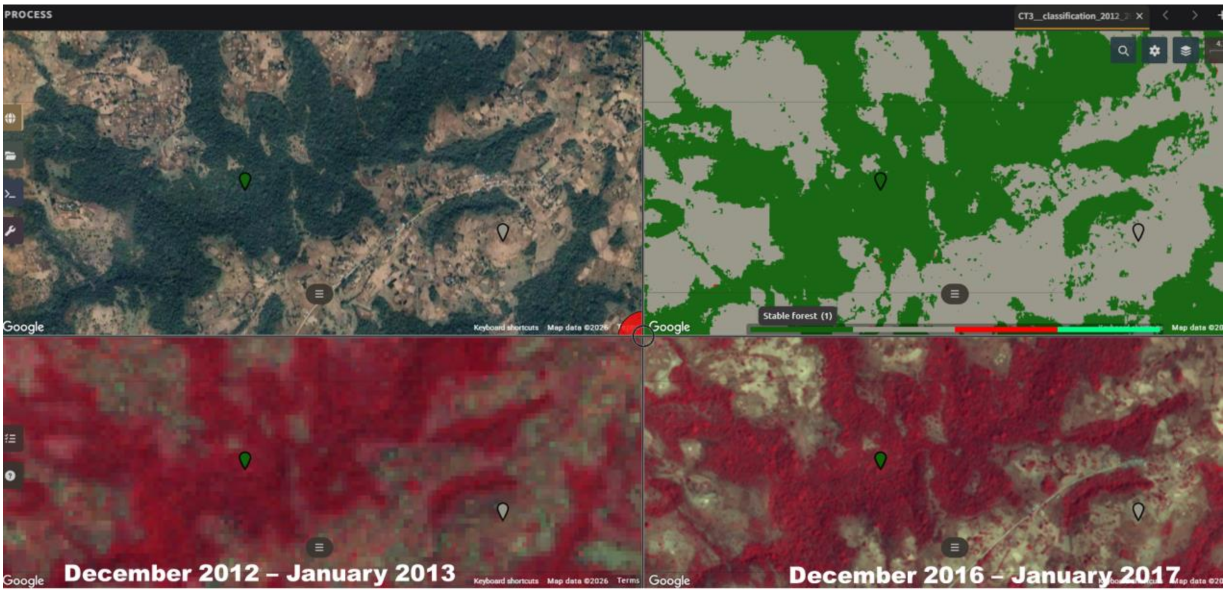

Figure 8: Training data collection for Stable forest and Stable non-forest in SEPAL for the period 2013 - 2017

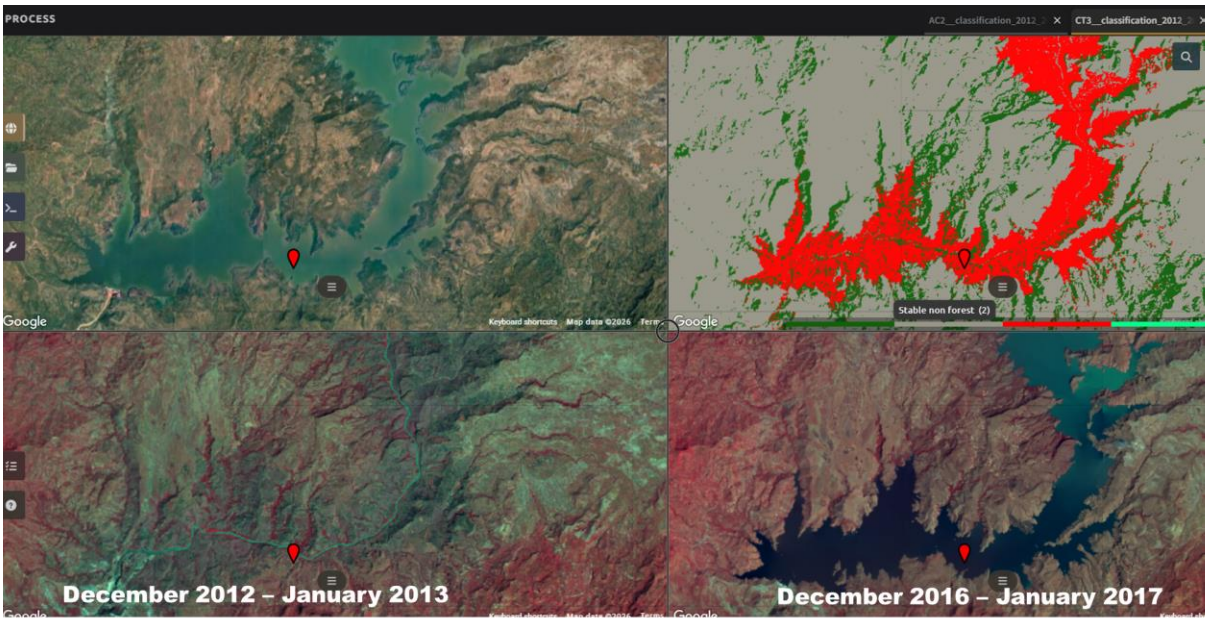

Figure 9: Training data collection for deforestation (Forestland converted to Wetland (Dam)) in SEPAL for the period 2013 - 2017

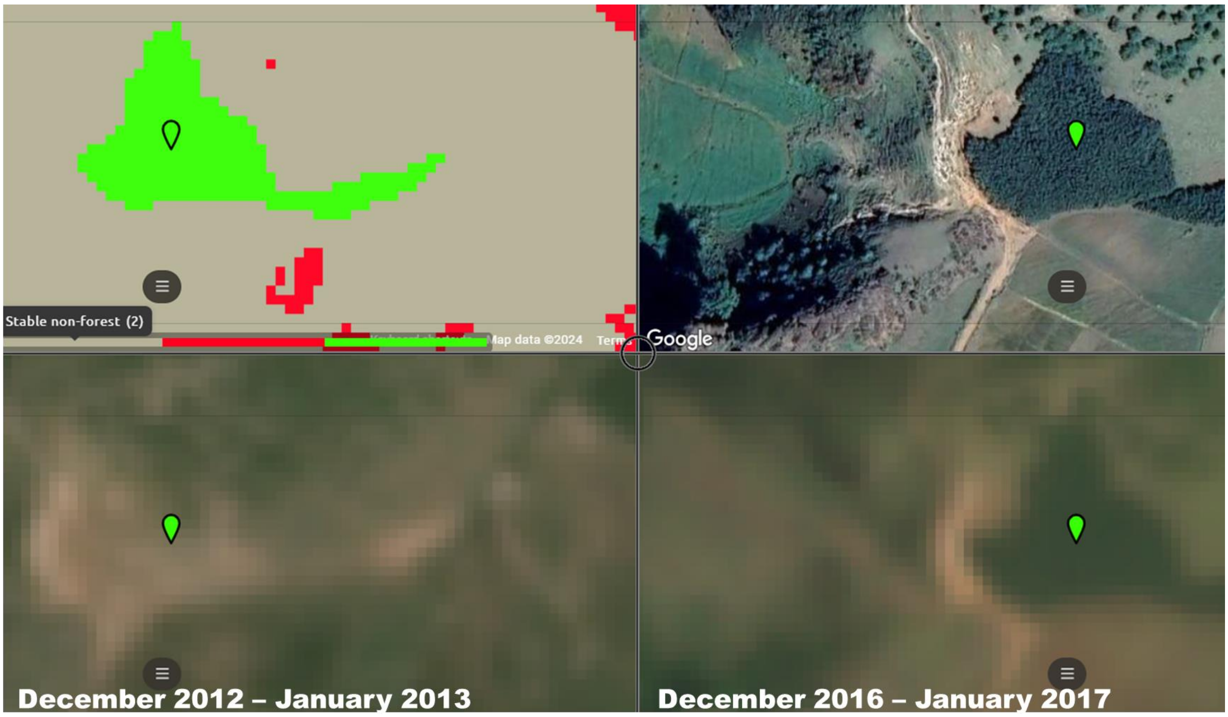

Figure 10: Training data collection for afforestation (Grassland converted to Forestland) in SEPAL for the period 2013 - 2017

8.3. Image classification and post classification editing

Post-classification change detection was deemed unsuitable because most historical land use/land cover (LULC) maps lack the accuracy required to reliably capture change. This method is particularly error-prone, as classification errors from individual dates are compounded when combined. Research has shown that while two forest/non-forest maps may each achieve high user accuracies (around 95%), the accuracy of the deforestation class in the resulting change map is often significantly lower, rendering post-classification estimates of forest change unreliable (Olofsson et al., 2013).

To address this limitation, Ethiopia adopted a supervised change detection approach using change training points (Tewkesbury et al., 2015). Accordingly, image-to-image change detection was applied in line with GFOI Guiding Principle 1 for remote sensing (GFOI, 2014): “When mapping forest (LULC) change, it is generally more accurate to detect change by comparing images processed with the same algorithm, rather than comparing maps derived from images.” Moreover, (Caccetta et al. 2011).

Stated also: "changes are more efficient monitored by comparing images as opposed to comparing maps derived from images"

In this framework, change detection classes are defined as either stable or change. Stable classes include forestland remaining forestland and stable non-forest, while change classes capture forest loss and forest gain.

The change assessment process analyzed satellite mosaics from 2013 and 2017 to evaluate forest cover dynamics over these periods. Target dates were selected to maximize vegetation cover while minimizing cloud interference. Classification employed spectral bands such as Near Infrared (NIR), Red, Green, and Blue, supplemented by auxiliary datasets including latitude, Shuttle Radar Topographic Mission (SRTM) terrain data (elevation, aspect, slope), and JRC Global Surface Water Mapping Layers. The integration of SRTM data proved particularly valuable given Ethiopia's complex topography (Farr et al., 2007).

Supervised classification was selected as the primary approach; whereby representative spectral samples are identified for each class in the imagery. Although automated classification methods were applied, extensive manual editing was required to correct misclassified pixels. The forest definition adopted a minimum mapping unit (MMU) of 0.5 ha, with biophysical thresholds set at ≥0.5 ha for forest patch area, ≥2 m for tree height, and ≥20% for canopy cover. To achieve the 0.5 ha MMU using Landsat 8 imagery (30 m resolution), 5 adjacent pixels were merged using the "sieve" algorithm in QGIS.

Post-classification manual editing was a critical step to minimize errors arising from spectral confusion or subtle differences between similar LULC types.

9. Methodological Approach for Stratified Area Estimation in Ethiopia

9.1. Activity Data Estimates

Activity data for deforestation, forest degradation and forest gain from natural forest restoration and commercial forest planting were derived using stratified area estimation based on the interpretation of sample plots. To generate these data, Ethiopia applied a stratified random sampling approach, consistent with internationally recognized good practices. Stratified area estimation, derived from the interpretation of sample plots, serves three key objectives. First, it provides a means to evaluate the accuracy of the map. Second, and most critically, it enables the generation of annual area change estimates, disaggregated by post-deforestation and pre-afforestation land use and land cover classes. Third, it supports the estimation of forest degradation areas.

By applying this methodology, the forestry sector is able to produce activity data (AD) that are fully compliant with IPCC guidelines, thereby meeting both national and international reporting requirements. The stratified area estimation was carried out in line with established methodologies to ensure results that are both statistically robust and transparently reported. The process incorporated a comprehensive sampling design, systematic sample allocation, and a clearly defined analysis protocol, as outlined below.

9.2. Sampling Design

A probability-based sampling design was applied, utilizing a stratified random sampling approach. Stratification was informed by a national-level map that distinguished four principal land cover and land cover change categories: stable forest, stable non-forest, forest gain, and forest loss. These categories served as the strata for the sampling framework. This stratification method reflects internationally recognized good practice, as it enhances the precision of class-specific accuracy and area estimates. It is particularly valuable for improving the reliability of estimates in less prevalent classes, such as forest gain and forest loss.

9.3. Sample Allocation

The distribution of sample units across the four strata—stable forest, stable non-forest, forest gain, and forest loss—was guided by a hybrid allocation strategy. This approach combined elements of proportional allocation with equal allocation, recognizing that each method carries inherent limitations. By integrating both, the design sought to balance representativeness and statistical robustness across all strata (FAO, 2016). Accordingly, the total number of calculated samples was allocated across the respective map classes as presented in Table 2.

Table 2: Distribution of samples across map classes (reference data collection)

	Map classes	Sample points per map class
1	Stable forest	1010
2	Stable non-forest	2130
3	Forest loss	532
4	Forest gain	528
	Total	**4200**

10. Map accuracy assessment

10.1. Reference (validation) data collection

Errors in the map classification were identified through visual interpretation of 4200 points using Very High Resolution (VHR) imagery from Google Earth via Collect Earth Online (CEO) (Figure 11). These datasets were used to assess the accuracy of the forest cover change map.

CEO, developed by the FAO under the Open Foris Initiative, is a free and open-source platform designed for collecting reference data from very high, high, and medium-resolution satellite imagery. The tool enables simultaneous visual interpretation of satellite imagery, offering global coverage through MapBox and Bing Maps, as well as access to diverse satellite data sources via Google Earth Engine (Figure 12).

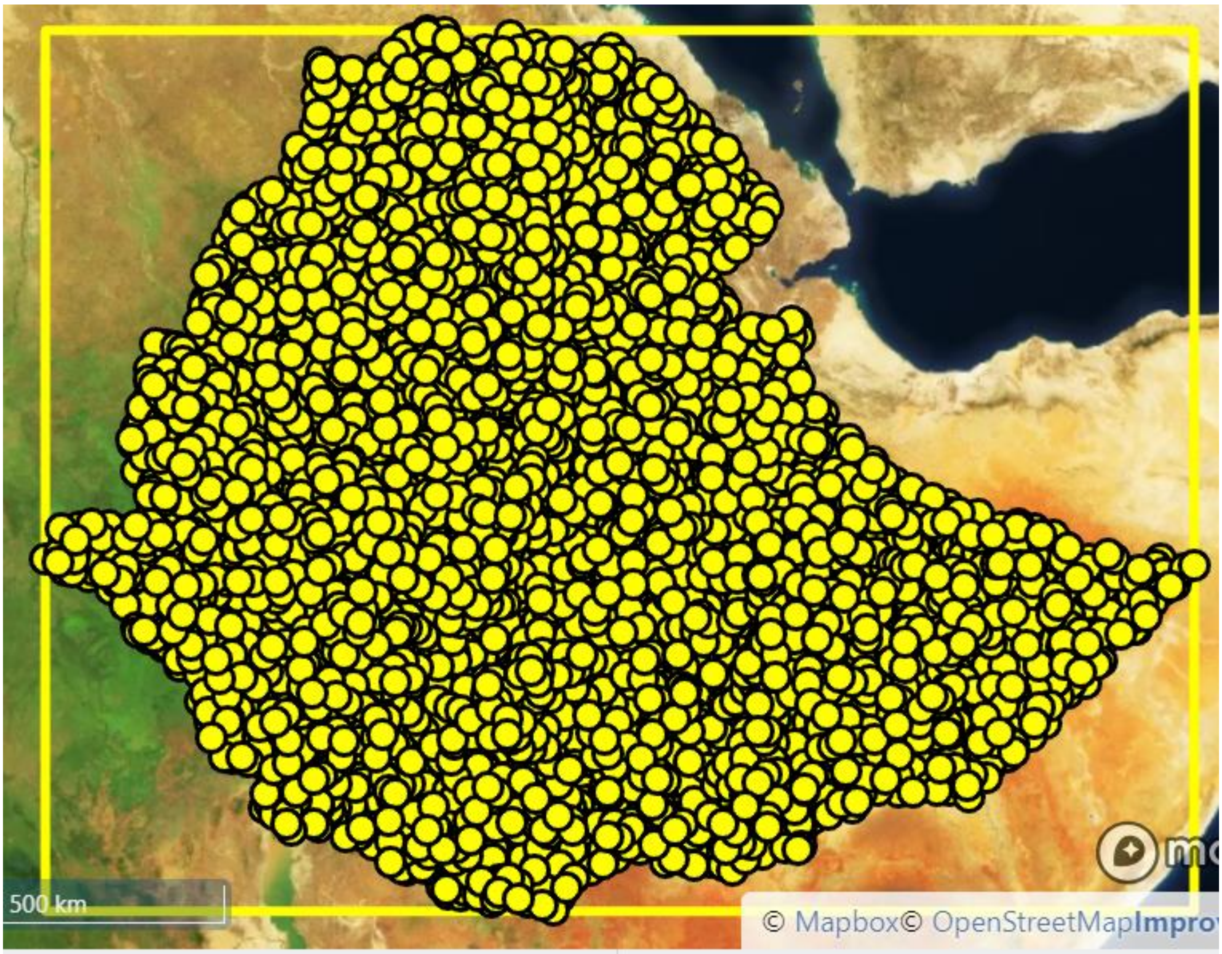

Figure 11: Reference points in CEO

Figure 12: CEO interface

According to the IPCC, countries are encouraged to follow good practice in producing emission estimates that:

1. Avoid systematic over- or underestimation of actual emissions to the extent possible, thereby minimizing bias.
2. Reduce uncertainties as far as practicable, taking into account national circumstances.

It is further considered good practice to quantify these uncertainties and report them transparently.

In line with this guidance, Ethiopia has undertaken an assessment of forest area loss and gain and stable forest affected by degradation to estimate emissions from deforestation and forest degradation, as well as removals from reforestation, and assisted natural regeneration. A comprehensive, wall-to-wall forest change map was developed for the period 2013–2017, categorizing land into four classes: forest loss, forest gain, stable forest (including forest degradation), and stable non-forest.

As with all surface estimations, errors are inevitable, with many tending to be systematic (bias). To address this, Ethiopia produced bias-corrected estimates of forest loss, forest gain, degradation and overall forest cover. Classification errors were identified using independently collected sample point data, separate from the training dataset. These sample points were used to verify whether classifications were accurate at specific locations. The results were summarized in an error matrix, which served as the basis for correcting the mapped areas in each class. This process yielded revised, bias-corrected area estimates.

To ensure transparency and rigor, Ethiopia also quantified and reported uncertainty by calculating confidence intervals around the bias-corrected estimates. The overall process of correcting for bias and validating the estimates is referred to as an accuracy assessment.

Ethiopia undertook the collection of reference sample data to validate the accuracy of map classifications at specific sample locations. These samples were derived through visual interpretation of points, using both time-series very high-resolution imagery and Landsat data. This interpreted information is referred to as reference data. To ensure reliability, only points with high user confidence in classification were retained, resulting in a total of 4,200 reference samples used for area estimation.

To assess map accuracy, an error matrix was applied, comparing the classified map outputs against the reference data. The overall accuracy was determined by calculating the proportion of samples where the map classification matched the reference data (represented by the **bold** diagonal counts in the matrix) relative to the total number of samples (the sum of all matrix cells) (Table 3).

Table 3: Error matrix of Ethiopia's forest cover change map 2013-2017

Error matrix for the change map 2013 - 2017		Classes	Reference				Total # points	User's Accuracy of class i	Commission error
			Stable Forest	Stable non-forest	Forest LOSS	Forest GAIN			100%
map	1	Stable Forest	**884**	117	4	5	1010	88%	12%
	2	Stable non-forest	50	**2080**	0	0	2130	98%	2%
	3	Forest loss	35	25	**471**	1	532	89%	11%
	4	Forest gain	37	58	10	**423**	528	80%	20%
		Total # points	1006	2280	485	429	4200		
		Producer's Accuracy of class i	88%	91%	97%	99%			
		Omission Error	12%	9%	3%	1%			
		Overall Accuracy	92%						

In the error matrix, the rows represent commission errors (over-detections), where the map incorrectly assigns a sample to a given class. For example, within the forest loss class, 532 samples were evaluated, of which 61 were over-detected. Specifically, these commission errors occurred when the map labeled samples as forest loss, while the reference data indicated otherwise:

- 1 sample was actually forest gain
- 35 samples were stable forest
- 25 samples were stable non-forest

Conversely, the columns capture omission errors (under-detections), where the map fails to identify a sample as belonging to a class. For instance, among 39 reference samples classified as forest loss, the map missed 14, assigning them to other categories instead.

The subsequent step involves quantifying these biases (both over- and under-detections) in terms of area (hectares) and applying corrections to the mapped estimates. This process yields bias-adjusted area estimates that more accurately reflect the true distribution of land cover change.

To correct map areas by class, the raw sample counts must first be expressed as proportions of the total samples within each map class (Table 4). For example, in the stable forest category:

884 out of 1,010 samples matched the reference data, corresponding to a proportion of 0.875

- 117/1,010 (0.116) were actually stable non-forest
- 4/1,010 (0.004) were forest loss
- 5/1,010 (0.005) were forest gain

These proportions are then used to translate sample counts into area estimates, ensuring that the final map reflects corrected values for both commission and omission errors.

Table 4: Error matrix as proportion of agreement and disagreements by total number of samples in each map class

Proportional matrix 2013 - 2017		Classes	Reference			
			Stable Forest	Stable non-forest	Forest LOSS	Forest GAIN
map	1	Stable Forest	**0.875**	0.116	0.004	0.005
	2	Stable non-forest	0.023	**0.977**	0.000	0.000
	3	Forest loss	0.066	0.047	**0.885**	0.002
	4	Forest gain	0.070	0.110	0.019	**0.801**

To derive the bias-corrected area estimates, the calculation began by multiplying the proportional error values from the corresponding rows of the error matrix (Table 5) with the mapped area of each class. This operation produced adjusted area values, which are presented in Table 6.

Table 5: Matrix which gives correct classification, omission under detection) and commission (over detection) errors expressed in corresponding map area (ha)

Area (ha) 2013 - 2017		Classes	Reference				Total
			Stable Forest	Stable non-forest	Forest LOSS	Forest GAIN	
map	1	**Stable Forest**	**22,930,764**	3,034,954	103,759	129,699	26,199,176
	2	**Stable non-forest**	2,037,167	**84,746,137**	-	-	86,783,304
	3	**Forest loss**	23,850	17,036	**320,951**	681	362,518
	4	**Forest gain**	12,828	20,109	3,467	**146,660**	183,065
		SAE (in ha)	**25,004,609**	**87,818,236**	**428,177**	**277,040**	**113,528,063**

SAE= Stratified Area Estimates

The bias-corrected area estimates, also called stratified area estimates, are obtained by the map area minus the over-detections (commission errors) plus the under-detections (omission errors).

Forest degradation was part of stable forest. All the reference points of stable forest were subject to interpretation whether there is forest degradation or not. Out of the 1,006 samples of stable forest of the reference data 18 were degraded forests.

The 90% confidence interval for the bias-corrected area estimates was derived by multiplying the standard error of the estimate by the factor 1.645006. The standard error itself was computed following Formula 11 in (Olofsson et al., 2014). The resulting confidence intervals are presented in the table 6 below.

Table 6: Bias-corrected area estimates (thousands of ha)

Classes	Bias corrected area (ha)	90 % Confidence interval (ha)	Confidence interval (% of adjusted area)
Forest loss	428,177	88,135	21%
Forest gain	277,040	96,044	35 %
Forest degradation	441,323	175,579	40%

The accuracy assessment indicates that, between 2013 and 2017, the estimated forest loss amounts to 428,177 hectares ± 88,135 hectares, while forest gain is estimated at 277,040 hectares ± 96,044 hectares. On an annual basis, this corresponds to an average forest loss of approximately 85,635 hectares per year and an average forest gain of about 55,408 hectares per year. Over the reference period (2013 and 2017), the estimated forest degradation amounts to 441,323 hectares ± 175,579 hectares. An annual forest degradation corresponds to about 88,265 hectares. These estimates serve as the activity data for subsequent analysis.

Each reference point was overlaid with a biome map to stratify the estimates of forest loss, forest gain, and overall forest cover by biome. In addition, the reference points were interpreted to determine the post-deforestation and pre-afforestation land use and land cover (LULC) classes. This stratification ensures that the activity data is disaggregated by LULC category, thereby enabling more accurate calculation of associated emissions and removals as per IPCC guidelines. Further details are provided in the accompanying Excel workbooks.

10.2. Analysis and Area Estimation

Reference data, comprising 4,200 sample plots, were visually interpreted using Collect Earth Online (CEO). Once reference data were collected for all sampled units, a detailed analysis was undertaken. An error matrix was then constructed, cross-tabulating the map classifications against the reference classifications for the sampled pixels. In line with good practice, the matrix was populated with estimated area proportions derived from unbiased estimators that account for the stratified sampling design.

Standard accuracy metrics—including overall accuracy, user's accuracy (the complement of commission error), and producer's accuracy (the complement of omission error)—were calculated for each of the four land cover classes as well as for the overall map.

A central element of the analysis was the estimation of areas for relevant land use and land use change classes, as required under ART-TREES. These estimates were derived from the reference classifications of the sample units, a method that provides more reliable and less biased results than relying solely on pixel counts from the map (Tables 7–10).

To quantify the uncertainty associated with these estimates, 90% confidence intervals were calculated, following recommended statistical procedures for design-based inference. The areas estimates and standard errors of the area estimates are presented in tables 7-10.

Table 7: Annual deforestation and forest degradation areas (in hectares) disaggregated by biome during the period 2013-2017

	Biome	2013	2014	2015	2016	2017	Total
Deforestation (ha)	*Acacia-Commiphora*	8859	6133	7496	4435	28,665	**55,588**
	Combretum-Terminalia	13,975	66,491	85,224	57,921	49,744	**273,354**
	Dry Afromontane	2044	3072	2726	34,117	6480	**48,439**
	Moist Afromontane	7842	6145	5451	17,036	14,322	**50,796**
	National total	**32,720**	**81,841**	**100,896**	**113,509**	**99,211**	**428,177**
Forest Degradation (ha)	*Acacia-Commiphora*	0	0	0	25,940	0	**25,940**
	Combretum-Terminalia	25,940	25,940	51,880	104,106	51,880	**259,745**
	Dry Afromontane	0	0	25,940	25,940	0	**51,880**
	Moist Afromontane	0	25,940	0	51,880	25,940	**103,759**
	National total	**25,940**	**51,880**	**77,819**	**207,865**	**77,819**	**441,323**

Table 8: The standard errors of annual deforestation and forest degradation areas (in hectares) disaggregated by biome during the period 2013-2017

	Biome	2013	2014	2015	2016	2017
Deforestation (ha)	*Acacia-Commiphora*	2429	2029	2239	1697	25,975
	Combretum-Terminalia	3012	26,408	26,584	5764	5413
	Dry Afromontane	1178	1403	1359	26045	2066
	Moist Afromontane	2265	1976	1915	3329	3032
Forest Degradation (ha)	*Acacia-Commiphora*	0	0	0	25,940	0
	Combretum-Terminalia	25,940	25,940	36,666	51,804	36,666
	Dry Afromontane	0	0	25,940	25,940	0
	Moist Afromontane	0	25,940	0	36,666	25,940

Table 9: Annual forest gain areas (in hectares) from natural forest restoration and commercial forest planting disaggregated by biome during the period 2013-2017

	Biome	2013	2014	2015	2016	2017	Total
Natural forest restoration (ha)	*Acacia-Commiphora*	4854	10,055	28,713	14,909	12,816	**71,347**
	Combretum-Terminalia	0	1387	693	2427	28,367	**32,874**
	Dry Afromontane	0	29,060	3814	7281	4854	**45,009**
	Moist Afromontane	0	693	347	52573	1734	**55,347**
	National total	**4854**	**41,195**	**33,567**	**77,190**	**47,771**	**204,577**
Commercial forest planting (ha)	*Acacia-Commiphora*	0	0	347	0	0	**347**
	Combretum-Terminalia	0	693	0	347	0	**1040**
	Dry Afromontane	347	5547	12,482	18,723	25,310	**62,409**
	Moist Afromontane	0	1734	1040	1387	4507	**8668**
	National total	**347**	**7974**	**13,869**	**20,456**	**29,817**	**72,463**

Table 10: The standard errors of annual forest gain areas (in hectares) from natural forest restoration and commercial forest planting disaggregated by biome during the period 2013-2017

	Biome	2013	2014	2015	2016	2017
Natural forest restoration (ha)	*Acacia-Commiphora*	1281	1817	25,958	2181	2098
	Combretum-Terminalia	0	691	490	912	25,956
	Dry Afromontane	0	25,960	1139	1558	1281
	Moist Afromontane	0	490	347	36,669	772
Commercial forest planting (ha)	*Acacia-Commiphora*	0	0	347	0	0
	Combretum-Terminalia	0	490	0	347	0
	Dry Afromontane	347	1367	2010	2416	2753
	Moist Afromontane	0	772	599	691	1236

11. Emission Factors

11.1. Description of National Forest Inventory of Ethiopia

Between 2014 and 2016, Ethiopia undertook a comprehensive National Forest and Landscape Inventory (NFI) as part of MRV Phase I project from 2013-2018. A key determinant of the quality and reliability of forest information lies in the selection and application of an appropriate sampling design. This design, together with robust data collection procedures, directly influences the accuracy and usability of information generated from the field, which in turn supports a wide range of decision-making processes. Recognizing this, Ethiopia's NFI placed strong emphasis on developing a sampling framework tailored to the country's specific context and its need for credible forest data. The outcomes and methodological details of the NFI were subsequently documented in Ethiopia's first FREL and FRL submission to the UNFCCC in 2017 (UN-REDD,2017).

11.2. Proposed Emission Factors

The emission factors for forestland have been derived from nationwide data collected through Ethiopia's National Forest Inventory (NFI, 2018). The analysis presents estimates of the average forest carbon stock across key carbon pools—Aboveground Biomass (AGB), Belowground Biomass (BGB), deadwood, litter, and Soil Organic Carbon (SOC)—along with their associated uncertainties. These results are detailed in Table 11, and illustrated in Figure 13.

Table 11: Forest carbon stocks in the five carbon pools with uncertainty estimates by biome

Forest types (Biomes)	AGB (tC/ha)	SE_{AGB} (tC/ha)	BGB (tC/ha)	SE_{BGB} (tC/ha)	DW (tC/ha)	SE_{DW} (tC/ha)	Litter (tC/ha)	SE_{L} (tC/ha)	SOC_{ref} (tC/ha)	SE_{SOCref} (tC/ha)
Acacia-Commiphora	26.696	12.079	9.400	4.253	1.049	0.711	1.041	0.714	38.436	6.284
Combretum-Terminalia	30.785	5.029	12.643	2.065	1.837	0.769	0.993	0.204	41.114	4.543
Dry Afromontane	53.768	20.163	14.523	5.446	1.925	1.465	1.206	0.628	53.971	5.758
Moist Afromontane	95.363	10.810	25.333	2.872	4.749	1.080	5.802	2.999	83.846	8.948

SE = Standard Error

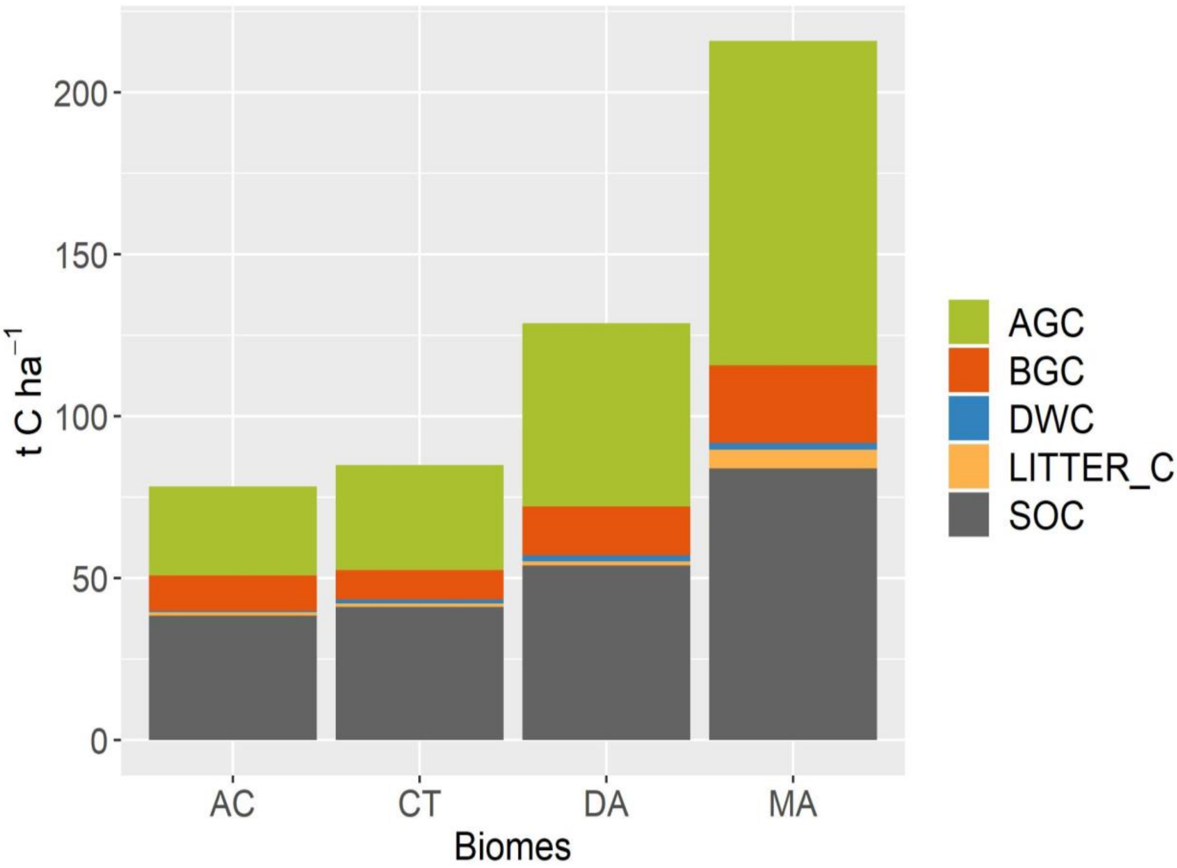

Figure 13: Carbon stock per biome for forestland

AC = *Acacia-Commiphora*; CT = *Combretum-Terminalia*; DA = Dry Afromontane; MA = Moist Afromontane

11.3. Emission Factors for Deforestation

Net emission factors (NEFs) for deforestation are calculated as the difference between the carbon stock of forestland and the average carbon stock of post-deforestation land use and land cover (Table 12). Estimates of forest carbon stocks, as well as those of land use and land cover following deforestation, are based on Ethiopia's National Forest Inventory (NFI) conducted between 2014 and 2016. Data on litter carbon and soil organic carbon (SOC) are drawn from the study "Evaluation of the Forest Carbon Content in Soil and Litter in Ethiopia", implemented by the Natural Resources Institute Finland (LUKE) and the Ethiopia Environment and Forestry Research Institute (EEFRI), covering the period August 2017 to February 2018 (Appendix 2, page 4).

The derivation of NEFs follows the methodological guidance provided in the IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006, IPCC, 2019). Uncertainty in carbon stock estimates across the various pools is assessed through sampling error analysis. Post-deforestation land use and land cover are determined by interpreting sample plots located within areas identified as deforested during the reference period of 2013–2017 (See the supporting excel workbooks for more details).

Table 12: Net emission factors (NEFs) for deforestation (tCO2e/ha)

		Post-Deforestation land use and land cover classes						
Biomes	**Forest types**	**Annual Cropland**	**Perennial Cropland**	**Mixed Annual & Perennial**	**Grassland**	**Settlement**	**Wetland**	**Other land**
Acacia-Commiphora	Natural Forest	154	-34	80	169	131	281	281
	Planted Forest	174	-14	100	190	151	301	301
Combretum-Terminalia	Natural Forest	186	-4	110	202	162	320	320
	Planted Forest	176	-14	100	192	153	311	311
Dry Afromontane	Natural Forest	289	90	204	308	264	460	460
	Planted Forest	188	-11	103	207	163	359	359
Moist Afromontane	Natural Forest	534	313	427	560	505	789	789
	Planted Forest	231	9	123	257	202	485	485

Note: The negative NEF indicates that *the post-deforestation land use carbon stock is higher than the pre-deforestation carbon stock*. According to TREES 2.0 requirements it is stated that: "*In instances where the post-deforestation land use carbon stock is higher than the pre-deforestation carbon stock, there can be no crediting for the net sequestration. Instead, the emissions shall be treated as zero".* Accordingly, all such negative emissions were treated as zero.

11.4. Emission Factors for Forest Degradation

For the forest degradation analysis, the plot level AG biomass (ton dry matter per hectare) in the plots in the Forest land were considered (NFI, 2018). The next step to was classify plot into two classes: Disturbed / Stable. The information about NFI plot disturbances was applied. A plot was regarded as “disturbed”, if the *human disturbance* in forest was "Heavily disturbed", "Moderately disturbed" or "slightly disturbed" or the forest was harvested (*Timber exploitation* in the NFI data) or branches top removal was taking place.

Emission factors for forest degradation are estimated by comparing the carbon stock of stable forest with that of disturbed forest following degradation events, calculated separately for each biome (Table 13). The average relative reduction in carbon stock was assessed across all plots affected by degradation during the reference period (2013–2017). The results indicate reductions of approximately 2% in *Acacia-Commiphora* forest, 32% in *Combretum-Terminalia* forest, 40% in Dry Afromontane forest, and 23% in Moist Afromontane forest (Table 13). Only AGB and BGB are considered for the analysis as per the IPCC guidelines (See the supporting excel workbooks for more details).

Table 13: Emission factors for forest degradation

Forest types (Biomes)	AGB & BGB carbon pools in Natural Forest (tCO_2e/ha) a	AGB in Stable Forest (t d.m./ha) b	AGB in Degraded Forest (t d.m./ha) c	Relative Difference (%) d = (b-c)/b	Forest Degradation EFs (tCO_2e/ha) e = a*d
Acacia-Commiphora	**132**	29	28	2%	**2.7**
Combretum-Terminalia	**159**	55	38	32%	**50.6**
Dry Afromontane	**250**	243	145	40%	**100.6**
Moist Afromontane	**443**	242	185	23%	**103.1**

12. Removal Factors

In the absence of biome-specific national removal factors for Ethiopia, carbon accounting for both natural forest restoration and commercial forest planting is conducted in line with established IPCC guidance.

For natural forest restoration, it is conservatively assumed that all carbon pools in tropical systems reach equilibrium within 20 years. Accordingly, the total biomass gain, including aboveground and belowground biomass, resulting from the conversion of non-forest land to forestland through assisted natural regeneration is averaged over this 20-year period to derive the annual carbon increment (Table 14).

For commercial forest planting, a different approach was adopted due to limited biome-specific inventory data. The mean annual volume increment of Ethiopia's five major plantation species—*Eucalyptus globulus* (Pohjonen and Pukkala, 1990), *Eucalyptus camaldulensis* (Gebretsadik, 2013), *Pinus patula* (Tesfaye et al., 2020), *Cupressus lusitanica* (Tesfaye et al., 2020), and *Acacia decurrens* (Ferede et al., 2019)—was applied. This increment was converted to aboveground biomass growth using IPCC biomass conversion and expansion factors (BCEFs) (Eggleston et al., 2006), while belowground biomass was estimated using standard root-to-shoot ratios. Biomass growth was then converted to carbon using the IPCC default carbon fraction.

For both natural forest restorations and commercial forest plantings pathways, changes in soil organic carbon (SOC) are calculated following IPCC Equation 2.25 (Eggleston et al., 2006, IPCC, 2019)) based on country-specific soil organic C stock values in the reference condition (SOC_{REF}) and IPCC default soil stock change values for land use (F_{LU}), management (F_{MG}) and input (F_{I}) using the default transition period between equilibrium SOC values, commonly 20 years.

EQUATION 2.25

ANNUAL CHANGE IN ORGANIC CARBON STOCKS IN MINERAL SOILS

$$\Delta C_{Mineral} = \frac{(SOC_0 - SOC_{(0-T)})}{D}$$

$$SOC_{Mineral} = \sum_{c,s,i} \left(SOC_{REF_{c,s,i}} \bullet F_{LU_{c,s,i}} \bullet F_{MG_{c,s,i}} \bullet F_{I_{c,s,i}} \bullet A_{c,s,i} \right)$$

(Note: T is used in place of D in the $\Delta C_{Mineral}$ equation if T is ≥ 20 years, see note below associated with the parameter D)

(See the supporting excel workbooks for more details).

Table 14: Removal factors (Including SOC sequestration) (tCO2e/ha/yr)

Biomes	Pre-Afforestation land use and land cover class	Natural Forest Restoration	Commercial Forest Planting
Acacia-Commiphora	Annual Cropland	8.28	41.42
	Grassland	8.73	41.87
	Wetland	13.66	46.80
Combretum-Terminalia	Annual Cropland	9.74	41.54
	Grassland	10.22	42.02
	Wetland	15.50	47.29
Dry Afromontane	Annual Cropland	14.86	42.10
	Grassland	15.49	42.72
	Wetland	22.41	49.65
Moist Afromontane	Annual Cropland	25.76	43.39
	Grassland	26.74	44.37
	Wetland	37.50	55.13

13. Standard Operating Procedures (SOPs) for data collection

13.1. SOPs for field data collection (Forest Inventory)

The Ethiopian Forestry Development (EFD) has prepared a comprehensive set of Standard Operating Procedures (SOPs) to support field data collection for the National Forest Inventory (NFI). Compiled into a dedicated field manual, these SOPs are designed for use by data collectors, inventory planners, trainers, and field supervisors engaged in the NFI process.

The manual outlines detailed, field-based protocols that encompass:

- Sampling design and plot layout – including the distribution and configuration of sampling units
- Field safety procedures and protocols for labeling and establishing inventory plots
- Measurement techniques for trees, deadwood, litter, soil carbon, crown parameters, and regrowth
- Data recording procedures for field measurements, observations, and interviews
- Organizational structure with clear roles and responsibilities for field teams
- Standardized field forms to ensure systematic and consistent data entry
- Recommended tools and techniques for biophysical assessments such as tree and soil measurements
- Guidance on GPS use for precise location referencing
- Qualitative data collection approaches, including guided discussions and interviews with key informants and local resource users

Serving as a cornerstone for Ethiopia's forest monitoring efforts, the SOP manual ensures methodological rigor, enhances data quality, and promotes consistency across all inventory activities.

13.2. SOP for Remote Sensing

The Ethiopian Forestry Development (EFD) has also established Standard Operating Procedures (SOPs) for monitoring deforestation, forest degradation, afforestation/reforestation, assisted natural regeneration, and for generating activity data.

In partnership with Wondo Genet College of Forestry and Natural Resources at Hawassa University, the Oromia Forested Landscape Programme (OFLP), FARM Africa Ethiopia, FAO, and the Spatial Informatics Group (SIG), EFD collaboratively developed a comprehensive Land Use and Land Cover (LULC), Land Use and Land Cover Change (LULCC), and

Forest Disturbance Interpretation Key for Ethiopia through a participatory process.

This interpretation key is a vital resource for interpreters, enabling precise identification of LULC types using remote sensing data and time-series analysis. Such capacity is fundamental for producing training datasets, validating algorithm outputs, and estimating activity data (AD) through sample-based approaches. By applying this methodology, interpreters can reliably classify IPCC LULC categories and monitor land-use changes using samples analyzed within Collect Earth Online (CEO).

13.3. SOPs for Quality Assurance and Quality Control (QAQC)

13.3.1. SOP for QAQC of Forest Inventory

The Ethiopian Forestry Development (EFD) has established Standard Operating Procedures (SOPs) to ensure the effective management and quality of National Forest Inventory (NFI) data, with particular emphasis on emission factors. As part of this initiative, EFD has developed a comprehensive QA/QC manual entitled Quality Assurance and Quality Control: National Forest Inventory of Ethiopia.

The overarching goal of the QA/QC process is to guarantee that all data collected meets minimum quality standards. Beyond this, QA/QC procedures provide critical feedback for refining measurement quality objectives (MQOs), improving data collection methodologies to reduce errors, strengthening training programs, and supporting the accurate interpretation of results.

The SOPs detail quality assurance and control measures across multiple stages of the inventory process, including field measurements, data entry, validation, storage, and archiving. Key provisions include field audits, real-time validation during data collection, and systematic rechecks to safeguard accuracy and reliability.

Data quality enhancement is integrated throughout the inventory cycle:

1. **Before fieldwork** – Comprehensive training equips field teams with the skills needed for precise data collection.

2. **During fieldwork** – Hot checks, cold checks, and regular team meetings provide QA/QC feedback, promote experience-sharing, and ensure consistency in practices.
3. **After fieldwork** – Unknown species are identified and categorized, while received data undergoes thorough review and cleansing to ensure accuracy.

Together, these measures uphold the integrity and reliability of Ethiopia's forest inventory data, ensuring it meets required standards and effectively supports national forest monitoring and reporting.

13.3.2. SOP for QAQC of Remote Sensing (RS)

The EFD has developed SOPs to effectively manage and ensure the quality of remote sensing data (activity data). As part of this initiative, it has produced a comprehensive QAQC manual titled *Quality Assurance and Quality Control (QAQC) for Forest Geospatial Monitoring*.

This manual establishes QAQC processes for GIS and Remote Sensing (RS) staff, aiming to maintain high-quality GIS and RS data. It provides a framework for identifying and rectifying errors, inconsistencies, and uncertainties in forest geospatial data, methodologies, and outputs. Ultimately, the manual ensures that all data and procedures meet the required standards and fulfill necessary technical and regulatory expectations.

14. Relevant Policy and Regulatory Framework, Strategies and Plans

Ethiopia's initiatives in natural forest restoration and plantation development are anticipated to significantly reduce both forest degradation and deforestation. In regions such as Tigray and parts of Amhara, the establishment of plantations as woodlots on farmers' own land has successfully met much of the demand for fuelwood (Ethiopia REDD+ Secretariat, 2015). This practice is expected to ease the pressure on natural forests.

Ethiopia has continuously developed policy frameworks to align environmental and economic development goals, in the view that all economic progress depends on Ethiopia's natural resources. Ethiopia has made significant steps toward its adaptation goals through the implementation of these policies and strategies. Here is how each has contributed:

- **Ethiopia's Climate-Resilient Green Economy (CRGE) Strategy**

Ethiopia's CRGE strategy prioritizes forestry in its low-carbon framework, targeting forest restoration for carbon/ecosystem benefits. This enabled forestry's integration into national climate pledges (NDCs).

- **National Forest Sector Development Program (NFSDP) (2018–2028)**

This ten-year program aims to transform Ethiopia's forest sector by promoting sustainable forest management, conservation, and reforestation. It was launched in 2018 by the then Ministry of Environment, Forest and Climate Change (MEFCC) with UNDP. Key components were Institutional Strengthening, Catalyzing Forest Sector Development, REDD+ Investment

It has created employment opportunities, improved livelihoods, and contributed to environmental protection by rehabilitating degraded lands and increasing forest cover.

- **Forest Development, Conservation and Utilization Policy and Strategy**

Ethiopia’s forest policy promotes forest cover expansion, conservation, and sustainable economic growth through initiatives like the National Forest Sector Development Program and Green Legacy Initiative. It addresses deforestation, fosters community participation, and engages the private sector to ensure sustainable forest resource management.

- **National REDD+ Strategy (2018–2030)**

Ethiopia's framework for reducing emissions from deforestation includes biodiversity and indigenous rights safeguards while promoting sustainable forest management. REDD+ pilots like the Oromia Forested Landscape Program have strengthened institutions, attracted international finance, and secured results-based payments from the World Bank and other partners.

- **Ten Years Development Plan (2021–2030)**

This plan outlines Ethiopia's vision for sustainable development, emphasizing climate resilience and environmental sustainability. It integrates adaptation measures into national development priorities, such as agriculture and forestry.

- **Ethiopian Bamboo Development Strategy and Action Plan (2019–2030)**

This strategy leverages Ethiopia's vast bamboo resources to promote green industries and sustainable livelihoods. By substituting bamboo for timber, it reduces pressure on forests, enhances ecosystem services, and supports climate resilience.

- **The Green Legacy Initiative (GLI)**

A large-scale tree-planting campaign launched in 2019, aiming to restore ecosystems and mitigate climate change by planting billions of trees.

- **Ethiopia’s Long-Term Low Emission and Climate Resilient Development Strategy (2020-2050)**

A blueprint for achieving net-zero emissions by 2050, focusing on sustainability, resilience, and cutting greenhouse gas emissions.

- **Nationally Determined Contribution (NDC3.0)**

Ethiopia's NDC 3.0 (2025–2035) targets a 70.3% emission reduction by 2035. Of this, 40.7% is unconditional, while the rest depends on international support. It aligns with Ethiopia's vision of net-zero emissions by 2050. Key focus areas include forestry (79.1% reduction), renewable energy, climate-smart agriculture, and circular economy.

- **Forest Development, Conservation and Utilization Proclamation (Proclamation No. 1065/2018)**

Ethiopia strengthened its legal framework for forest protection and commercial forestry, recognizing private and community forests. It enabled forest registration and provided incentives for sustainable management by investors and local communities.

- **Forest Regulation No. 544/2024**

Enhancing carbon sequestration through forest conservation, restoration, and sustainable management. Supporting Ethiopia's participation in carbon markets and finance mechanisms while strengthening forest governance and promoting sustainable livelihoods.

- **Ethiopian National Drylands Restoration Strategy**

The Strategy aims to rehabilitate and sustainably manage the country's dryland ecosystems, which have been historically neglected.

- **The Green Legacy and Degraded Landscape Restoration Special Fund proclamation 1361/2024**

Ethiopia has established the Green Legacy and Degraded Landscape Restoration Special Fund through a new proclamation aimed at financing environmental restoration efforts. This fund serves as a permanent financial mechanism to support the rehabilitation of degraded landscapes, afforestation, and reforestation initiatives. Ethiopia First REDD+ Safeguards Information Summary Report

- **Ethiopia First REDD+ Safeguards Information Summary Report**

Ethiopia’s First REDD+ Safeguards Information Summary Report (2021) outlines how the country has addressed and respected the Cancun Safeguards in implementing its REDD+ strategy. It highlights Ethiopia’s national safeguards approach, institutional arrangements, grievance mechanisms, and efforts to ensure transparency, participation, and benefit-sharing in forest-related climate actions.

- **Ethiopia's National Carbon Market Strategy**

Ethiopia’s National Carbon Market Strategy (2025–2035) sets out a roadmap for the country to engage in international and domestic carbon markets, aiming to mobilize climate finance for renewable energy, forestry, clean cooking, green industry, and e-mobility. It aligns with Article 6 of the Paris Agreement and builds legal, institutional, and technical systems to ensure high-integrity participation and equitable benefit-sharing.

15. Emissions and Removals

Ethiopia's Crediting Level for the 2018–2022 period was established using a combination of the Removals Approach and the Emissions Reduction Methodology. This calculation incorporates Ethiopia's restoration achievements under the REDD+ framework, integrating high-quality activity data, biome-specific biomass estimates, and emission and removal factors consistent with IPCC guidelines. The methodology reflects Ethiopia's ecological diversity, practical implementation realities, and adherence to internationally recognized best practices, ensuring a credible and transparent quantification of greenhouse gas (GHG) impacts. Removals were aggregated from natural forest restoration and commercial forest planting activities activities, stratified by biome. Emissions were estimated from observed deforestation and forest degradation, with activity data linked to biome-specific emission factors.

Annual estimates were derived as follows:

- **Emissions** (t CO_2e): calculated by multiplying net emission factors by activity data for each activity, then summing emissions from deforestation and forest degradation (Table 15, Figure 14).
- **Removals** (t CO_2e): calculated by multiplying net removal factors by activity data for commercial forest planting and natural forest restoration, aggregated annually (Tables 16, Figure 15).

Table 15: Annual emissions from deforestation and forest degradation

Reference year	Emissions (t CO_2e)
2013	9,927,905
2014	21,732,898
2015	30,141,749
2016	43,822,640
2017	28,572,530

Table 16: Total annual removals from natural forest restoration and Commercial Forest Planting per biome per year

	Biome	2013	2014	2015	2016	2017	Total
Total GHG Removals from NFR (tCO2)	*Acacia-Commiphora*	-42,383	-129,555	-508,219	-637,773	-751,080	**-2,069,010**
	Combretum-Terminalia	0	-14,012	-21,101	-45,746	-323,306	**-404,164**
	Dry Afromontane	0	-448,787	-506,112	-615,610	-688,173	**-2,258,683**
	Moist Afromontane	0	-18,203	-27,474	-1,407,530	-1,453,546	**-2,906,752**
	Total	**-42,383**	**-610,556**	**-1,062,905**	**-2,706,660**	**-3,216,105**	**-7,638,609**
Total GHG Removals from CF (tCO2)	*Acacia-Commiphora*	0	0	-14,362	-14,362	-14,362	**-43,085**
	Combretum-Terminalia	0	-28,970	-28,970	-43,372	-43,372	**-144,683**
	Dry Afromontane	-14,595	-248,551	-774,408	-1,562,756	-2,628,409	**-5,228,719**
	Moist Afromontane	0	-75,220	-120,351	-180,866	-376,437	**-752,874**
	Total	**-14,595**	**-352,741**	**-938,090**	**-1,801,355**	**-3,062,579**	**-6,169,360**

The reference level is calculated here based on the approach given in TREES 2.0.

The reference level for total emissions from deforestation and forest degradation is estimated at **27,082,832** t CO_2e based on the average emissions during the period 2013-2017 (Table 15, Figure 14).

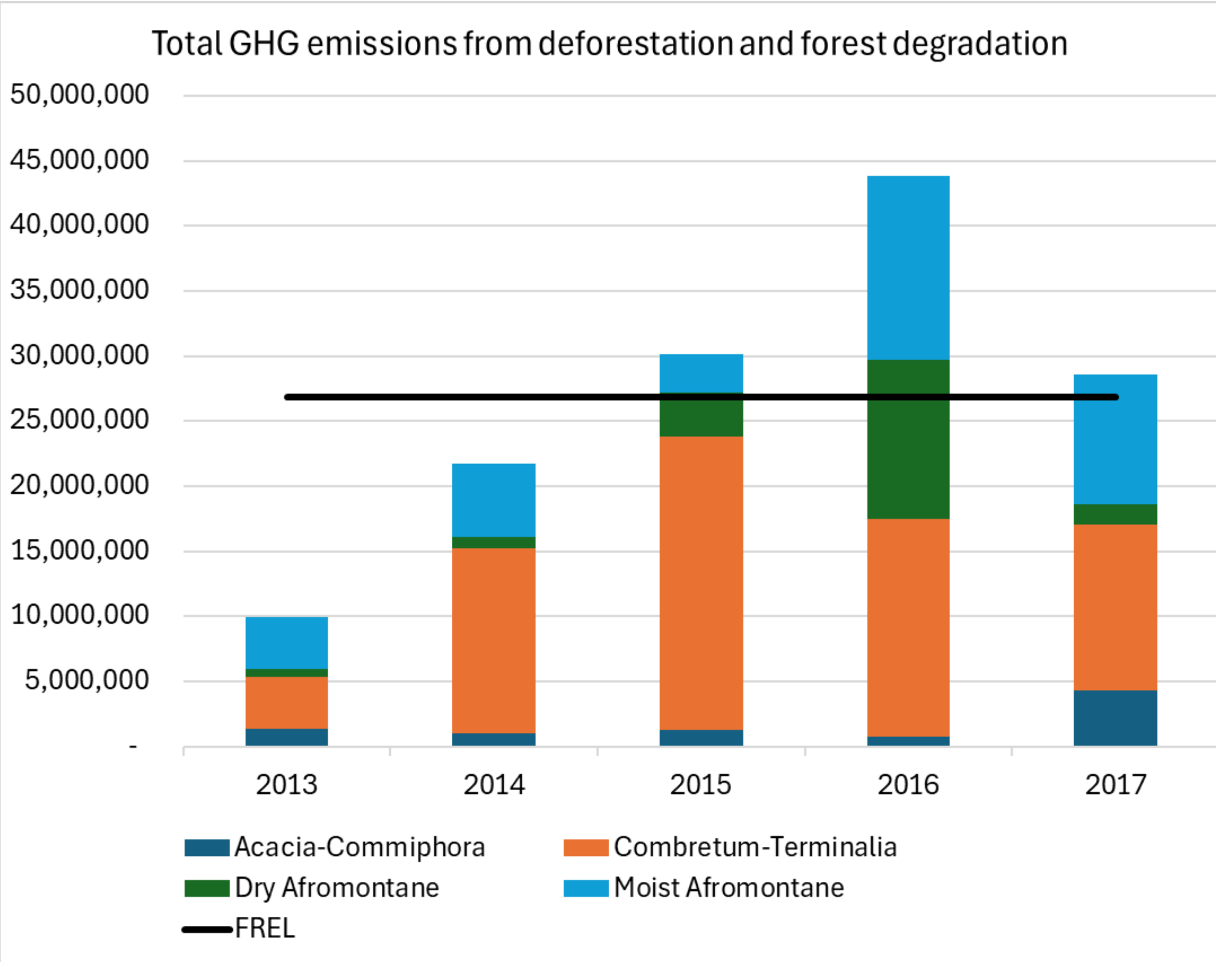

Figure 14: Reference emissions level

However, ART-TREES uses an area-based reference level for commercial forest planting, which is not in line with the UNFCCC modalities for reference level construction since these "…need to be expressed in tons of carbon dioxide equivalent per year" (Decision 12/CP17). As such Ethiopia is proposing the average removals associated with the average area planted over the reference period to convert the ART-TREES baseline to an equivalent UNFCCC reference level. As such, the reference level for removals from commercial forest planting is estimated at **-1,233,872** t CO_2e based on the average cumulative removals during the historical period (Table 17, Figure 15).

Table 17: Removals reference level for commercial forest planting for each biome

Hist. AVG GHG REMV from CF	**AVG 2013 -2017**
Acacia-Commiphora	-8,617
Combretum-Terminalia	-28,937
Dry Afromontane	-1,045,744
Moist Afromontane	-150,575
AVG GHG REMV from CF	-1,233,872

CF = Commercial Forest

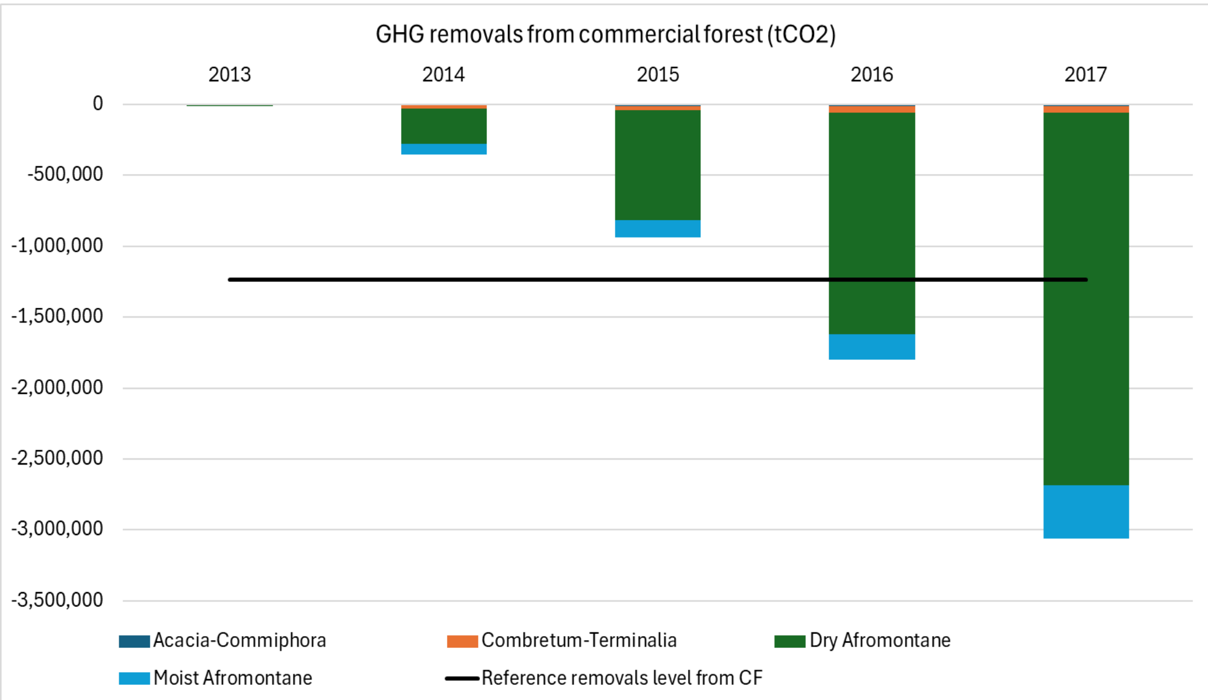

Figure 15: Reference removals level from commercial forest planting (CF)

For natural forest restoration, TREES 2.0 suggests the following: "*All new areas of natural forest restoration reported under ART are eligible for crediting; and, upon entering ART the incremental growth that occurs during the crediting period, on all areas of natural forest restored up to ten (10) years prior to the start of the crediting period start date is eligible for removals crediting.*" This approach is proposed for UNFCCC reporting as well. The total GHG removals from natural forest restoration (NFR) are estimated at -7,638,609 tCO2 for the period 2013-2017 (Table 16). These removals were calculated for all areas of natural forest restoration and reflect the incremental growth that occurred in each year of the reference period.

All calculations, parameters, and data inputs described are documented in the Excel Workbooks (Annex 1), ensuring full transparency, auditability, and consistency with the requirements.

16. Proposed Forest Reference Emission Level and Forest Reference Level

Ethiopia proposes a Forest Reference Emission Level based on average annual emissions and removals over the period 2013-2017 assessed by AD x EF and AD x RF, respectively. The emissions from deforestation and forest degradation in the FREL and FRL are assessed at **27,284,780** t CO_2e/yr while the removals from commercial forest plantation are assessed at **- 1,031,504** t CO_2e/yr.

17. Uncertainty calculations

Uncertainty estimates were calculated at the 90% confidence level. To combine and propagate errors, a Monte Carlo simulation approach was applied, enabling the derivation of annual emission reductions together with associated uncertainty ranges.

The assessment of uncertainty was conducted through Monte Carlo simulations (n = 10,000), addressing the following components:

- Stratified area estimates
- Carbon pools
- Carbon fraction
- Root-Shoot ratios
- Removal factors
- Biomass Conversion and Expansion Factors (BCEFs)

90% confidence intervals were applied to both area and emissions/removals estimates.

18. Updating Frequency

To maintain the accuracy of the Forest Reference Emission Level (FREL) and Forest Reference Level (FRL) in light of evolving socio-economic conditions and the availability of new or improved data, the FRL will be subject to periodic revision. It may be updated more frequently as necessary to reflect improved methodologies and data inputs.

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