REDD+ Technical Annexure

(Modified Submission)

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Forest Monitoring and Information Division
Department of Forests and Park Services
Ministry of Energy and Natural Resources
Royal Government of Bhutan

REDD+ Technical Annexure Pursuant to Decision 14/CP.19

Results achieved by Bhutan from reducing emissions from deforestation, sustainable management of forests, conservation of forest carbon stocks, and enhancement of forest carbon stock

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1. Introduction

Bhutan is pleased to submit REDD+ Technical Annex to its First Biennial Transparency Report (BTR) within the context of results-based payments for activities aimed at reducing emissions from deforestation and forest degradation, conserving forest carbon stocks, sustainable management of forests, and enhancing forest carbon stocks in developing countries (REDD+), under the United Nations Framework Convention on Climate Change (UNFCCC).

Bhutan emphasizes that this submission of Technical Annex, which presents the results of REDD+ actions, is voluntary and solely intended to demonstrate the performance and secure result-based payments, in line with Decision 13/CP.19, paragraph 2, and Decision 14/CP.19, paragraphs 7 and 8. Consequently, this submission does not modify, revise, or otherwise alter the Nationally Determined Contributions (NDCs) voluntarily submitted by Bhutan under the UNFCCC Paris Agreement.

This submission pertains to the reference level outlined in Bhutan's Forest Reference Emission Level (FREL) and Forest Reference Level (FRL), as per Decision 13/CP.19, which was approved following a technical assessment in 2020. Bhutan notes that the Technical Annex covers four activities: reducing emissions from deforestation, conservation of forest carbon stocks, sustainable management of forest, and enhancing carbon stocks, as described in the FREL and FRL. This document highlights Bhutan's achievements in these four REDD+ activities from 2015 to 2023 across the country.

This submission consists of the summary of information from the technical assessment report, results on emission scenario and enhancement of removal, methodological consistency between results and assessed FREL and FRL. This report has been prepared by the Department of Forests and Park Services (DoFPS), Ministry of Energy and Natural Resources (MoENR) who were involved in the development of the assessed FREL and FRL.

2. Summary Information from the Technical Assessment Report of FREL and FRL

2.1 Background

The Royal Government of Bhutan, through the DoFPS under the then Ministry of Agriculture & Forests, has developed a comprehensive FREL and FRL to serve as benchmarks for assessing the performance of REDD+ activities under the UNFCCC framework. This initiative was aimed to enhance Bhutan's commitment to reducing greenhouse gas emissions and promoting sustainable management of forests as outlined in its NDC.

The primary objective of Bhutan's FREL and FRL was to take the emissions and removals from the forestry sector and establish a baseline for measuring future performance. The FREL and FRL was submitted to UNFCCC in January 2020[1]. Based on the recommendation of the Technical Assessment Team in June 2020, a modified FREL and FRL was submitted in December 2020[2]. Subsequently, the Technical Assessment of Bhutan's FREL and FRL was completed and the report published by the UNFCCC Secretariat on its REDD+ website[3].

Bhutan's FREL and FRL include four REDD+ activities: reducing emissions from deforestation, sustainable management of forests, conservation of forest carbon stocks, and enhancement of forest carbon stocks. It does not include reduced emission from forest degradation, however, all carbon fluxes from the forest are covered through these four REDD+ activities accounted in the FREL and FRL. Further, degradation is indirectly accounted for, considering that the main drivers of forest degradations are already included in the FREL and FRL.

The FREL for deforestation is constructed by calculating historical average emissions from deforestation and incorporating an upward adjustment of 0.1% of biomass carbon stock, as applicable to countries with high forest cover and low deforestation. The FRL includes net removals from SMF, conservation, and enhancement activities without adjustment.

The carbon pools considered in Bhutan's FREL and FRL include above-ground biomass (AGB), below-ground biomass (BGB), dead wood, litter, and soil carbon. Non-CO_2 emissions from forest fires, such as CH_4, CO, and N_2O, have also been included as CO_2 equivalents to ensure comprehensive accounting of all emissions and removals.

The construction of the FREL and FRL adhered to the guidelines set forth by the IPCC and UNFCCC. Activity data for deforestation under the FREL were generated using Landsat imagery through remote sensing technology. Timber removals from sustainable management of forests and conservation activities were quantified based on timber harvest records maintained by the DoFPS and published annually. Emission factors were derived from NFI 2015 data. The historical reference period for Bhutan spans from 2005 to 2014, divided into two contiguous periods (2005-2009 and 2010-2014).

The total annual historical emission from deforestation is 159,781 tCO_2-e yr^{-1}. The 0.1% adjustment from biomass carbon is 335,331 tCO_2-e yr^{-1}, and the adjustment from delayed emission from soil organic carbon (SOC) is 10,725 tCO_2-e yr^{-1}. Therefore, the final FREL for Bhutan is 505,837 tCO_2-e yr^{-1}.

The total emission from SMF, including timber extraction and forest fire, is 3,302,580.87 tCO_2-e for 2005-2009 and 3,024,836.07 tCO_2-e for 2010-2014. The removal (carbon sequestration) from

[1] https://redd.unfccc.int/files/national_frel_frl_bhutan-3.pdf
[2] https://redd.unfccc.int/files/final_bhutan_frel_frl_20201207_for_webposting.pdf
[3] https://unfccc.int/sites/default/files/resource/tar2020_BTN.pdf

SMF is -13,147,307.10 tCO_2-e yr^{-1}. Emissions from timber harvest in conservation areas are 206,259.46 tCO_2-e for 2005-2009 and 181,785.17 tCO_2-e for 2010-2014. The removal from conservation activities is -5,255,503.35 tCO_2-e yr^{-1}. The total CO_2 removals by plantations during 2005-2014 are estimated to be significant. The FRL of Bhutan is –8,539,085 tCO_2-e yr^{-1}.

2.2 Information on the assessed FREL and FRL

FREL and FRL was subject to technical assessment by UNFCC and Table 1 provides a summary of Bhutan's assessed FREL and FRL.

Table 1: Summary of the assessed FREL and FRL

Contents	Description
Scale	Nationwide
Forest area	2.7 million hectares
REDD+ activities[8]	Includes 4 activities: (1) Reducing emissions from deforestation; (2) Conservation of carbon stock; 3) Sustainable management of forests; and 4) Enhancement of carbon stock from reforestation/plantation
Carbon pools included[9]	AGB, BGB, Dead organic matter (DoM), SOC
Gases included	CO_2. Non-CO_2 gases (CH4, N2O, CO, etc.) accounted in forest fires
Reference period	2005-2014
Activity data	Activity data was estimated using the IPCC Approach 2. To generate deforestation activity data for Bhutan, three national Land Use and Land Cover (LULC) datasets—LUPP 1995, LCMP 2010, and LULC 2016—were reviewed but found inconsistent due to differing methodologies and resolutions. Therefore, the Global Forest Change dataset (Hansen et al., 2013) was used to generate LULC maps. Annual tree cover loss and gain were integrated with a 2000 tree canopy cover baseline to produce two contiguous maps covering the periods 2004–2009 and 2010–2014. Pixel-level data were aggregated to the minimum mapping unit through zonal statistics. Stratified area estimation was then conducted to derive the final activity data, effectively reducing uncertainties while accounting for the actual forest loss during the reference period despite net increase in total forest area.

Emission factor/ removal factor	IPCC Tier 1 and 2 methodology was used to determine the emission or removal factors. The forest carbon density from the NFI 2015 is assumed to be lost on the land use conversion i.e., deforestation. The emission factors are determined using the **Gain-Loss method on land conversion.** It is assumed that there is a complete loss of biomass carbon when forest land is converted to non-forest land categories (except for grassland). In case of conversion from Forest land to Grassland, no loss of biomass of shrubs, herbs, DOM and BGB is considered. In absence of land category specific SOC density for Cropland, Settlement, Grassland and Other Land, the SOC density for new land use category was estimated using IPCC default stock change factor and 20 years transition period (IPCC, 2006b). The biomass/carbon density for the different pools are estimated through the following ways: ● Country-specific allometric equations for timber were used to estimate AGB for individual trees. ● Mokany et al. (2006) equations for root-to-shoot ratios and carbon fraction (IPCC 2006) were applied to calculate BGB and carbon stocks. ● Coarse woody debris (CWD) Volume per unit area is estimated and converted into biomass using wood density and the decay class reduction factor. ● Litter carbon was estimated as the dry weight of the litter sample. ● SOC was determined through the Walkley-Black method using the titrations for all samples except the soil samples with very high SOC content, which are analyzed using the CHN Analyzer.
FREL	505,837 tCO_2-e yr^{-1}
FRL	–8,539,085 tCO_2-e yr^{-1}
Uncertainty	***Activity data***: LULC maps of 2004-2009 and 2010-2014 have an accuracy of 70% and 72% respectively. Deforestation area was estimated Hansen Product with a confidence interval of ±211.04 ha for 2004–2009 and ±622.20 ha for 2010–2014. The annual average deforestation was calculated with a confidence interval of ±65.96 ha. The uncertainty for the wood removals, forest fires, and plantation areas was estimated using the expert elicitation process and were documented in the FREL and FRL submitted to UNFCCC. ***Emission factor/removal factor (EF/RF)***: Emission factor/removal factor uncertainty was estimated using the error propagation method from the

	margin of error information from the NFI and other sources data. ***Annual CO_2 emissions/removals:*** The uncertainties for annual emissions/removals were estimated using a propagation method.
Model applied	Historical average + adjustment for FREL Historical average for FRL
Adjustment according to the national circumstances	An adjustment has been proposed to FREL by adding 0.1% of carbon stock and delayed emission from soil.

2.3 Bhutan's FREL/FRL and adjustment

The FREL and FRL for Bhutan's REDD+ includes a Forest Reference Emission Level of +**505,837 tCO_2-e yr^{-1}** (Figure 1) and a Forest Reference Level of **-8,539,085.79 tCO_2-e yr^{-1}** (Figure 2) respectively**.** Without adjustment to the national circumstances, the annual average emission from deforestation is **159,780 tCO_2-e yr^{-1}.**

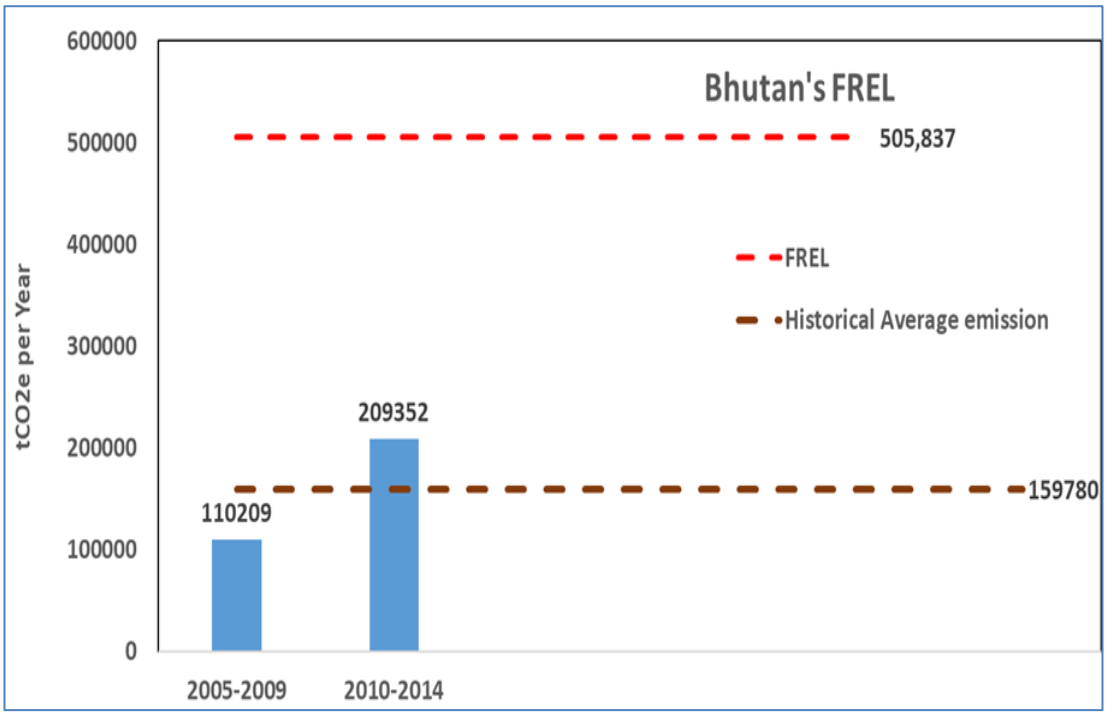


Figure 1: FREL of Bhutan

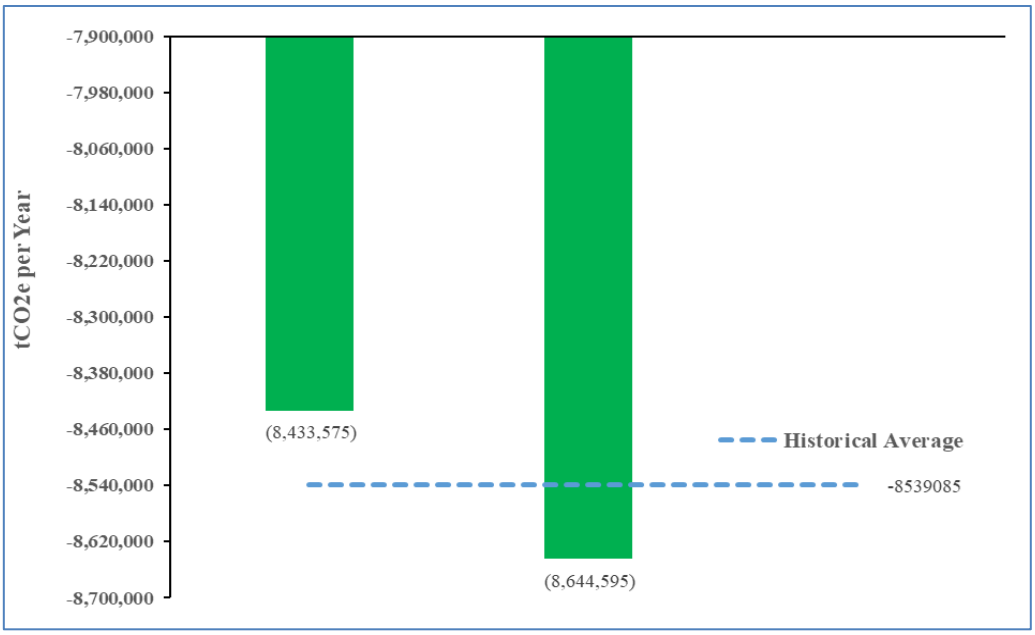


Figure 2: FRL of Bhutan

2.4 Technical Assessment of FREL/FRL

The UNFCCC Technical Assessment Report of the proposed FREL and FRL recognized Bhutan's efforts to improve the transparency of the input data for FREL and FRL construction. The report also commends Bhutan for showing a strong commitment to the continuous improvement of its FREL/FRL estimates in line with the stepwise approach. The Technical Assessment Report provides following recommendations to Bhutan for further FREL and FRL improvement:

- Use of a consistent approach to geospatial image interpretation across the time series
- Harmonization of the activity data and emission factors used between the GHG inventory and the FREL and FRL submission
- Provision of time-series information on forest and land-use transitions
- Use of time-series consistent data in the estimation of carbon stock densities
- Inclusion of non-biomass pools in FREL and non-CO_2 gases in FRL

3. Results of Emission Reductions and Enhancement of Removals

The National REDD+ Strategy and Actions Plan of Bhutan was approved in 2020 which will be implemented over the period of 20 years depending on the availability of the budget and national circumstances. Bhutan represents the results on FREL and FRL from 2015 to 2023 for nine years (one year less than 10 years reference period) despite the limited implementation of the REDD+ Strategy and Action Plans.

3.1 Emission Reductions/Removal Enhancements From 2015 to 2023

From 2015 to 2023, significant changes in forest land were observed, primarily due to landslides, forest fires, and developmental activities. The analysis also reveals considerable misclassification of forest areas in earlier assessments, leading to some areas being mistakenly recorded as deforestation based on maps. which were This was subsequently corrected in the recent, more accurate maps and as a result, there has been no measurable reduction in CO_2 emissions from deforestation.

Conversely, the recent National Forest Inventory (NFI) indicates that biomass growth within forests has increased, leading to a net increase in CO_2 removals through conservation, sustainable management of forests, and forest enhancement activities.

3.2 Annual Emission and Removals

Annual average emission from all REDD+ activities from 2015-2023 is 2,086,107.44 $tCO_2e\ yr^{-1}$ with deforestation contributing 1,563,891.142 $tCO_2\ yr^{-1}$ and emission due to wood removal and forest fires is 522,214.50 t CO_2-e yr^{-1} from forest outside protected areas (sustainable management of forests) and forest inside protected areas (conservation of carbon stock). The annual average removal is -11,272,037.00 $tCO_2\ yr^{-1}$. Table 2 provides a summary of emission and removals from four REDD+ activities included in FREL and FRL of Bhutan.

Table 2: Emissions and Removals During 2015-2023

REDD+ Activity	Total Emission (tCO_2-e)	Total Removal (tCO_2-e)
Deforestation	14,075,020.28	
Sustainable Management of Forests	4,238,251.49	-69,109,802.11
Conservation of Forest Carbon Stock	461,695.17	-32,206,215.11
Enhancement of forest carbon stock		-132,315.75
Total	**18,774,966.93**	**-101,448,332.97**
Average (tCO2e/yr)	**2,086,107.44**	**-11,272,037.00**

Deforestation has increased from 2015 to 2023 in comparison to 2005-2014 thus resulting in a net increase in emission from deforestation. The total baseline emission for nine years based on the assessed FREL is 4,552,533 t CO_2 while total emission from the deforestation from 2015- 2023 is 14,075,020.28t CO_2 for nine years, which is 9,522,487.28 t CO_2 greater than the FREL indicating a poor performance. This increase in emission is attributed to landslides and development activities including expansion of agricultural land on privately owned lands besides misclassifications in the past. Table 3 shows comparison of performance against the FREL from 2015 – 2023. The total average emissions in the reporting periods are very close to the projected emissions in the assessed FREL derived from the key driver of deforestation (Table 23 of assessed FREL) based on 11th and

12th Five Year Development Plan. This indicates that historical deforestation trends may not adequately reflect future emission scenarios in high forest, low deforestation countries like Bhutan.
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Table 3: Annual Net Emission Reduction During 2015-2023 (t CO_2-e)

Year	REDD+ Activity		Total Emission	FREL	Performance
	Deforestation - Biomass	Deforestation - SOC			
2015	1,559,935.84	26,082.99	1,586,018.84	505,837.00	(1,080,181.84)
2016	1,559,935.84	40,762.27	1,600,698.12	505,837.00	(1,094,861.12)
2017	1,559,935.84	55,441.55	1,615,377.40	505,837.00	(1,109,540.40)
2018	1,424,570.31	74,148.92	1,498,719.23	505,837.00	(992,882.23)
2019	1,424,570.31	92,856.29	1,517,426.60	505,837.00	(1,011,589.60)
2020	1,424,570.31	111,563.66	1,536,133.97	505,837.00	(1,030,296.97)
2021	1,424,570.31	130,271.03	1,554,841.34	505,837.00	(1,049,004.34)
2022	1,424,570.31	148,978.40	1,573,548.71	505,837.00	(1,067,711.71)
2023	1,424,570.31	167,685.76	1,592,256.07	505,837.00	(1,086,419.07)
Total	**13,227,229.41**	**847,790.87**	**14,075,020.28**	**4,552,533.00**	**(9,522,487.28)**
Average	**1,469,692.16**	**94,198.99**	**1,563,891.14**	**505,837.00**	**(1,058,054.14)**

Despite the increase in deforestation, there was an improvement in forest management which is indicated by the annual biomass increment data from the 2nd NFI Report. As per the assessed FRL, the net removal from sustainable management of forests, conservation of carbon stock and enhancement of forest carbon stock is **-76,851,765.00 t CO_2** for nine years. During the same period, the total net removal is estimated to be **-96,748,386.31 t CO_2,** which is **19,896,621.31 tCO_2** more than the FRL. Table 4 shows comparison of performance against the FRL from 2015 – 2023.

Table 4: Annual Net Removal From 2015 to 2023 (t CO_2-e)

Year	Total Emission	Total Removal	Net Removal	FRL	Performance
2015	487,121.81	(11,340,335.11)	(10,853,213.30)	(8,539,085.00)	2,314,128.30
2016	780,154.15	(11,321,480.41)	(10,541,326.26)	(8,539,085.00)	2,002,241.26
2017	603,838.85	(11,302,625.71)	(10,698,786.86)	(8,539,085.00)	2,159,701.86

2018	258,819.94	(11,286,822.73)	(11,028,002.79)	(8,539,085.00)	2,488,917.79
2019	616,846.31	(11,271,019.76)	(10,654,173.44)	(8,539,085.00)	2,115,088.44
2020	294,261.86	(11,255,216.78)	(10,960,954.92)	(8,539,085.00)	2,421,869.92
2021	502,254.22	(11,239,413.80)	(10,737,159.58)	(8,539,085.00)	2,198,074.58
2022	598,904.31	(11,223,610.82)	(10,624,706.51)	(8,539,085.00)	2,085,621.51
2023	557,745.20	(11,207,807.85)	(10,650,062.65)	(8,539,085.00)	2,110,977.65
Total	**4,699,946.66**	**(101,448,332.97)**	**(96,748,386.31)**	**(76,851,765.00)**	**19,896,621.31**
Average	**522,216.30**	**(11,272,037.00)**	**(10,749,820.70)**	**(8,539,085.00)**	**2,210,735.70**

3.3 Uncertainties of Emission and Removals

From 2015 to 2023, the annual average emissions from deforestation amounted to 1,563,891.14 t CO_2, with a combined uncertainty of 11.11%. In comparison, the annual average net removals from conservation, sustainable management of forests, and enhancement is -10,749,820.70 t CO_2, with a combined uncertainty of 10.33%. Table 5 presents the uncertainty associated with the annual average emissions and removals for the period 2015-2023.

Table 5: Uncertainty of Annual Average Emissions and Removals for 2015-2023

Category	Value (tCO2e)	Uncertainty (%)
FREL	505,837.00	23.95
Annual emissions (2015-2023)	1,563,891.14	11.11
Annual emission reductions (2015-2023)	-1,058,054.14	**10.23**
FRL	-8,539,085.00	11.53
Annual removals (2015-2023)	-10,749,820.70	10.33
Annual removal enhancements (2015-2023)	2,210,735.70	7.69
Net annual emission reductions (2015-2023)	**1,152,681.56**	**14.75**

4. Demonstration of Consistency in Methodologies Used to Generate Results with FREL and FRL Assessment Methodologies

The REDD+ results method is overall consistent with the FREL and FRL (Table 6). Both methods use the same forest definition and LULC classification, and share the same REDD+ activities, carbon pools, gases, scope and scale.

Table 6: Consistency Between Submitted FREL and FRL, and REDD+ Results

Methods	FREL and FRL construction	Calculation of REDD+ results
Forest definition		Same definition.
Land and forest classification	-Six IPCC land Categories -No sub-classification	Same.
REDD+ activities	- Reducing emissions from deforestation - Sustainable management of forests - Conservation of Forest Carbon Stock - Enhancement of Forest Carbon Stock.	Same REDD+ activities.
Carbon pools	- AGB, BGB, SOC, DOM.	Same carbon pools. It may be noted that only AGB of trees and sapling are included in the non-CO_2 gases emission resulting from the forest fire in consistent with assessed FRL and FREL.
Gases	- CO_2 and Non -CO_2 from Forest Fire (CH_4, CO, N_2O)	Same.
Scale	- Nationwide	Same.
Accounting period	- 2005-2014	2015- 2023
Activity data (AD)	- Activity data (deforestation) were generated using Landsat imagery and Global Forest Watch dataset. The deforestation was estimated as a map difference followed by the stratified area estimation based on Olofson et al. (2014). - A reliable estimate of deforestation was achieved through the stratified area estimation analysis. Two sets of change maps (2005-2009) and 2010-2014 were produced using the global forest watch map products. The total deforested area was divided by 5 years in each case to achieve annual deforestation area during the reference period.	- Similar methodology was followed to generate the activity data (deforestation). Activity data was derived by change detection between two time periods and produced two change maps for 2015-2017 and 2017-2023 using the land use and land cover maps of 2015, 2017 and 2023 produced using the Landsat imagery. The reliable deforestation area was obtained by stratified area estimation method based Olofson et al. (2014). Therefore, deforestation area for reference and reporting period are consistent. - Wood removals from the fire disturbance area and sustainable management of forest and Conservation area were obtained from records maintained by DoFPS.

	- Wood removals from fire disturbance area and sustainable management of forest and Conservation area were obtained from records maintained by DoFPS.	
Emission factor/ removal factor	14 country-specific allometric equations are used to calculate AGB of individual trees. Default IPCC root-to-shoot ratios (e.g., Mokany *et al.* (2007) and carbon fraction are applied to calculate BGB and to convert biomass to carbon. Carbon stock densities in forest were assumed to have oxidized instantaneously on deforestation.	The DoFPS have developed 35 country-specific allometric equations for the National Forest Inventory Volume II: State of Forest Carbon Report[4]. However, to maintain the consistency with the assessed FREL/FRL, the carbon density is calculated using the 14 species specific and two general equations as used in the NFI-I or assed FREL/FRL to maintain the consistency. Default IPCC root-to-shoot ratios (e.g., Mokany *et al.* (2007) was applied; average AGB at national level was used to recalculate the BGB for Trees and Sapling roots, which was applied at plot level in the NFI Volume- II: State of Forest Carbon Report 2023.The carbon fraction of 0.47 is applied to convert biomass into carbon. Biomass carbon stock densities in forest were assumed to have oxidized instantaneously on deforestation.
Annual emissions and removals	Annual Emission and Removals area estimated by **Gain-Loss Method.** The emissions and/or removals of a LULC conversion or deforestation in the reference period are calculated by multiplying the activity data with corresponding EF/RF. Emissions/ removals are then summed across all conversions for each 5-year period and the average emissions/removals for the 5-year periods are then divided by 5 to generate annual emissions/removals. Lagged emission from SOC was also estimated	Annual Emission and Removals area estimated by **Gain-Loss Method.** The emissions and/or removals of a LULC conversion in a period are calculated by having activity data for such conversion multiplied by the corresponding EF/RF. Emissions/ removals are estimated for each year from 2015 to 2023 and summed across all conversions for each 9-year reporting period. Lagged emission from SOC was also estimated
Uncertainty	Uncertainties are estimated using approach 1 - error propagation method described 2006 IPCC Guidelines	Uncertainties are estimated using approach 1 - error propagation method described 2006 IPCC Guidelines

[4] National Forest Inventory Volume II: State of Forest Carbon Report (https://www.dofps.gov.bt/download/4424/?tmstv=1767582435)

5. Description of the National Forest Monitoring System and Institutional Roles and responsibilities for measuring, reporting and verifying the results

5.1 National Forest Monitoring System (NFMS)

National Forest Monitoring System (NFMS) is a comprehensive framework designed to track and evaluate the state of a country's forest resources. The NFMS integrates various components which consist of Satellite Land Monitoring System (SLMS), NFI, National GHG Inventory and online platform for information sharing and monitoring. NFMS operates under the principles of transparency, consistency and accuracy, ensuring that collected data aligns with international standards such as those outlined by the IPCC. The following diagram illustrates the ideal NFMS.

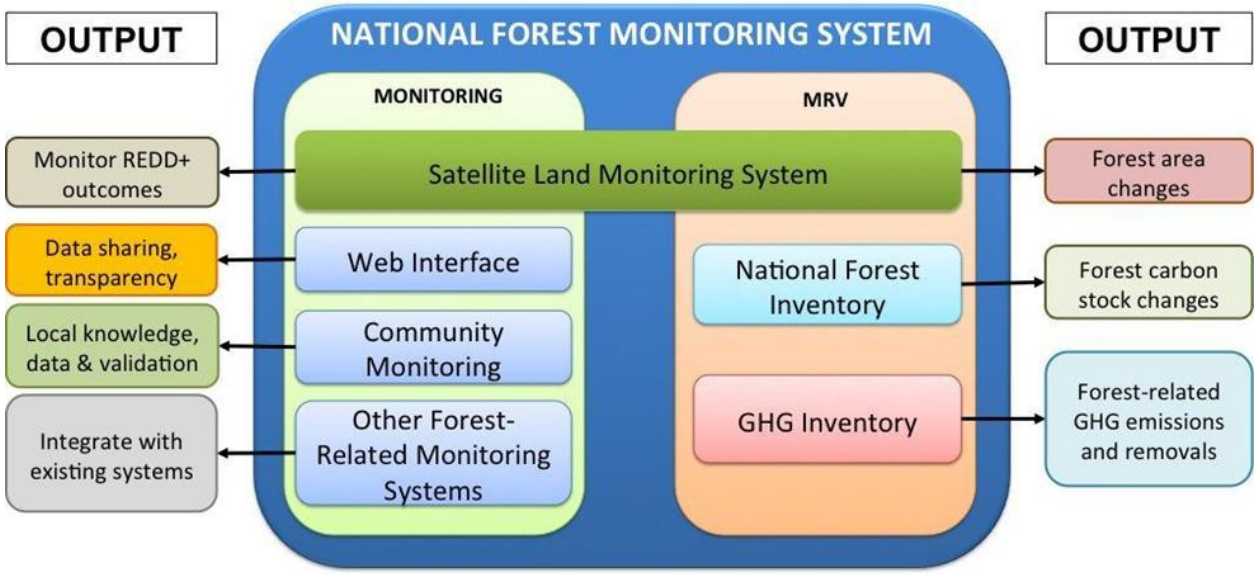


Figure 3 NFMS System in place

The three technical pillars or building blocks of the NFMS that are essential to support the MRV function are:

Pillar 1: A Satellite Land Monitoring System (SLMS)

SLMS employs advanced remote sensing technologies to monitor LULC changes efficiently and cost-effectively. By using satellite imagery, it provides consistent, spatially explicit data over time, reducing the need for extensive ground-based surveys. A key function of SLMS is generating AD to quantify LULC changes, crucial for estimating greenhouse gas emissions and removals. This makes SLMS a vital tool for climate change mitigation, enabling temporal consistency for historical trend analysis and future predictions. Its scalability and robustness support applications at national, regional, and global levels.

In Bhutan, while REDD+ result-based payment activities have not been implemented, SLMS can play a pivotal role if adopted. It supports robust reporting and verification processes aligned with

international frameworks like the UNFCCC. Designed to capture data on both anthropogenic and natural changes using freely available satellite imagery, SLMS generates periodic LULC maps, including forest type and canopy density maps. These outputs complement the NFI, enhancing the understanding of forest dynamics in Bhutan and supporting sustainable management of forests.

Pillar 2: National Forest Inventory (NFI)

The NFI is a vital tool for ensuring sustainable management of forests and conservation in Bhutan and crucial ground-based data collection exercise to assess and monitor the changes in forest carbon stock in different pools.

NFI of Bhutan is designed to provide accurate information about the size, distribution, composition and condition of our forests including the carbon stocks and changes taking place in the forest cover the time through periodic measurement. NFI entails systematic sampling design with 2424 permanent cluster plots laid at 4km x 4km grid and it is designed to be measured at an interval of 5-10 years. NFI covers both forest and non-forest land in Bhutan and it is a probabilistic sampling approach such that each land use has equal opportunity of being sampled. The NFI also enhances the understanding of forest ecosystems by collecting comprehensive data beyond timber resources. It includes information on non-wood forest products, shrubs, herbs, biodiversity, forest health and disturbance. This multidimensional approach supports the sustainable use of forest resources while preserving ecological balance.

The NFI is coordinated and conducted by the DoFPS. The Department has completed two cycles of the NFI between 2012-2015 and 2021-2022 to assess the extent of forest cover and the condition of forest resources.

Pillar 3: GHG Inventory

The GHG Inventory is an estimation of a country's GHG emissions and removals, making it a critical and mandatory component of the reporting requirements under the UNFCCC. The GHG inventory involves estimating emissions from various sources and removals by sinks, adhering to the principles of Transparency, Accuracy, Consistency, Comparability, and Completeness (TACCC principles).

Emission in the forestry sector results from deforestation, timber removals and forest fire. These activities are directly linked to the national GHG inventory, which provides comprehensive emissions and removals in different sectors and cover detailed information from Agriculture, Forestry and Other Land Use (AFOLU). The emission and removal estimates derived from the GHG inventory are included in Bhutan's National Communication and Biennial Update Report submitted to the UNFCCC, forming part of the formal reporting process.

Despite its establishment, currently the components of the NFMS framework function and exist as separate standalone systems and are supported by the existing DoFPS systems for data gathering

and sharing. For instance, the information on forest resources is maintained in an online repository called the Forest Information Reporting and Monitoring System (FIRMS). Patrolling and forest offence activities are recorded using Spatial Monitoring and Reporting Tool (SMART) which supplements FIRMS in providing spatial data. Spatial data is maintained in a geodatabase and shared through a web-portal. Further, Spatial Decision Support System (SDSS) which is a web-based interactive tool allows DoFPS to rationalize and monitor forest area being lost to other developmental activities through the issuance of forestry clearance. Thus, there is a need to have a common platform to bring the required information from all these systems so that information on NFMS can be accessed and shared through a single window.

5.2 Roles and Responsibilities

The DoFPS, under the MoENR, serves as the overall coordinator for REDD+ implementation. The National Forest Monitoring System is managed by DoFPS. Both NFI and GHG (forestry sector) inventory are implemented by the DoFPS, while Satellite land monitoring is carried out by both DoFPS and the National Land Commission Secretariat (NLCS). DoFPS and NLCS collaboratively develop periodic LULC maps. However, monitoring of forest disturbance arising from both anthropogenic and natural calamities is undertaken solely by DoFPS leveraging on the remote sensing technologies as well as ground truthing.

At the national level, the institutions involved in MRV for REDD+ include DoFPS, NLCS and Department of Environment and Climate Change (DECC). DoFPS leads the SLMS, NFI and GHG Inventory for the preparation of FREL/FRL. Quality Assurance and Quality Control (QAQC) is carried out by the DoFPS by forming the QAQC member to review the procedure and assessing data quality. The measurement report is submitted to DECC which is further reviewed and finally submitted to UNFCCC.

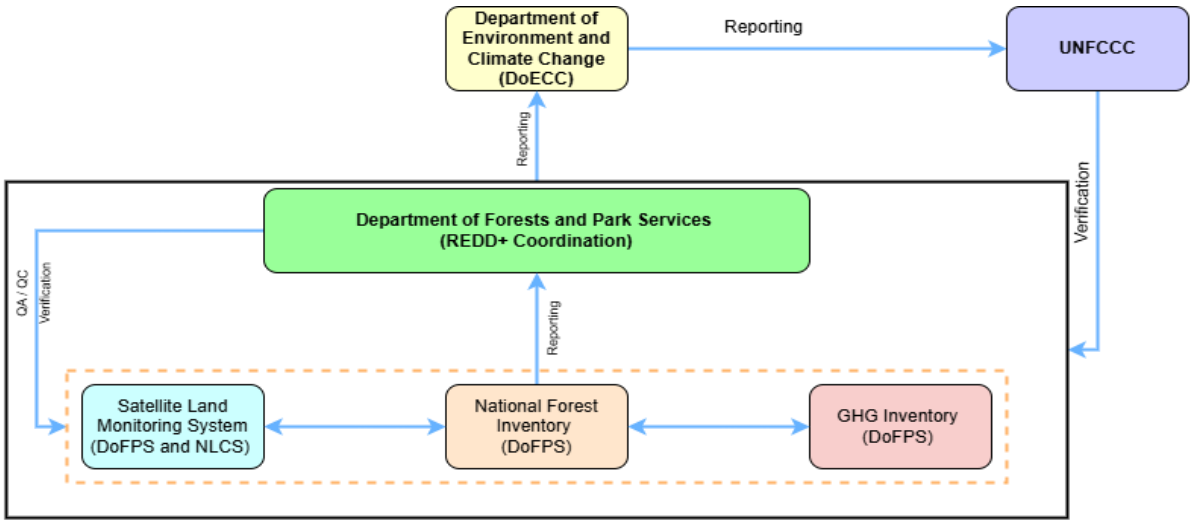


Figure 4: Institutional arrangement for NFMS

6. Necessary Information to Allow for the Reconstruction of the Results

6.1 Deforestation

Three land use and land cover maps (2015, 2027 and 2023) produced using the Landsat data were used to understand the extent of deforestation. A change analysis was conducted to determine the extent of deforestation between two periods and produced two set of change maps for 2015-2017 and 2017 to 2023. All the maps were produced using the end of year mainly from November to January of two overlapping years. Therefore, 2015 map provides all information at the end of 2015 year, 2017 provides information at the end of 2017 year and 2023 provides information at the end of year 2023.

The map area of forest losses was validated through series of desktop exercise, field validation and stratified area estimation as described in subsequent sections. The stratified areas of deforestation are used for estimation of emission.

6.1.1 Activity Data

To derive the activity data, existing LULC map of 2015 (Figure 5), and two new maps for the year 2017 (Figure 6) and 2023 (Figure 7) were generated using Landsat imagery. Three Landsat 8 scenes cover the entire geographical area of Bhutan. Sample data for training the model and for accuracy assessment were extracted from the NFI, high resolution satellite imagery (Google Earth), and geolocation points from field visits. The sample data was divided into training samples (80%) and validation samples (20%). The training samples were used exclusively for model development, while the validation samples were used solely for accuracy assessment. The two datasets were independent, with no overlap between training and validation samples. Image segmentation was performed in eCognition (version 9.1.3) using the multi-resolution segmentation algorithm.

. For classification, the Random Forest classifier in the eCognition was applied. Random Forest is a machine learning algorithm commonly used for LULC mapping. Six land classes were generated consistent with IPCC land categories. Tables 7, 8 and 9 show the land cover statistics for year 2015, 2017 and 2023.

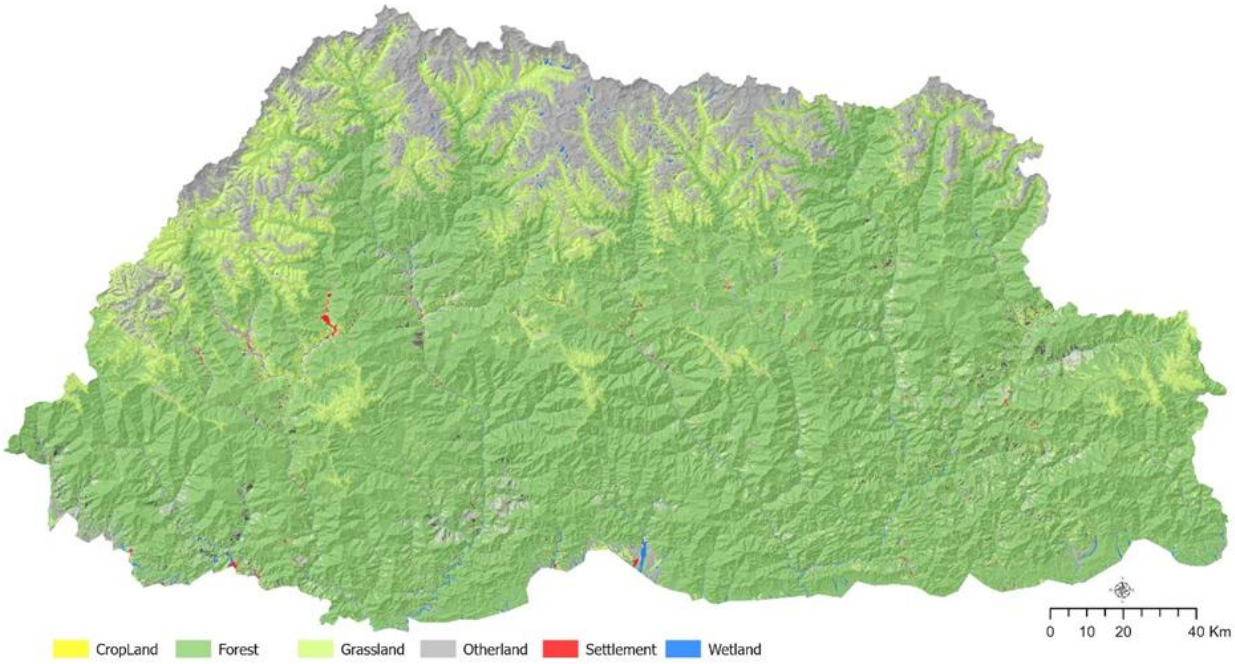


Figure 5: Land Use and Land Cover Map 2015

Table 7: Land Use and Land Cover Classes (2015)

Class	Area (ha)	Area %
Cropland	105716.11	2.75%
Forest	2705402.96	70.46%
Grassland	616681.40	16.06%
Other land	379044.24	9.87%
Settlement	7465.21	0.19%
Wetland	25090.08	0.65%
Total	3839400.00	

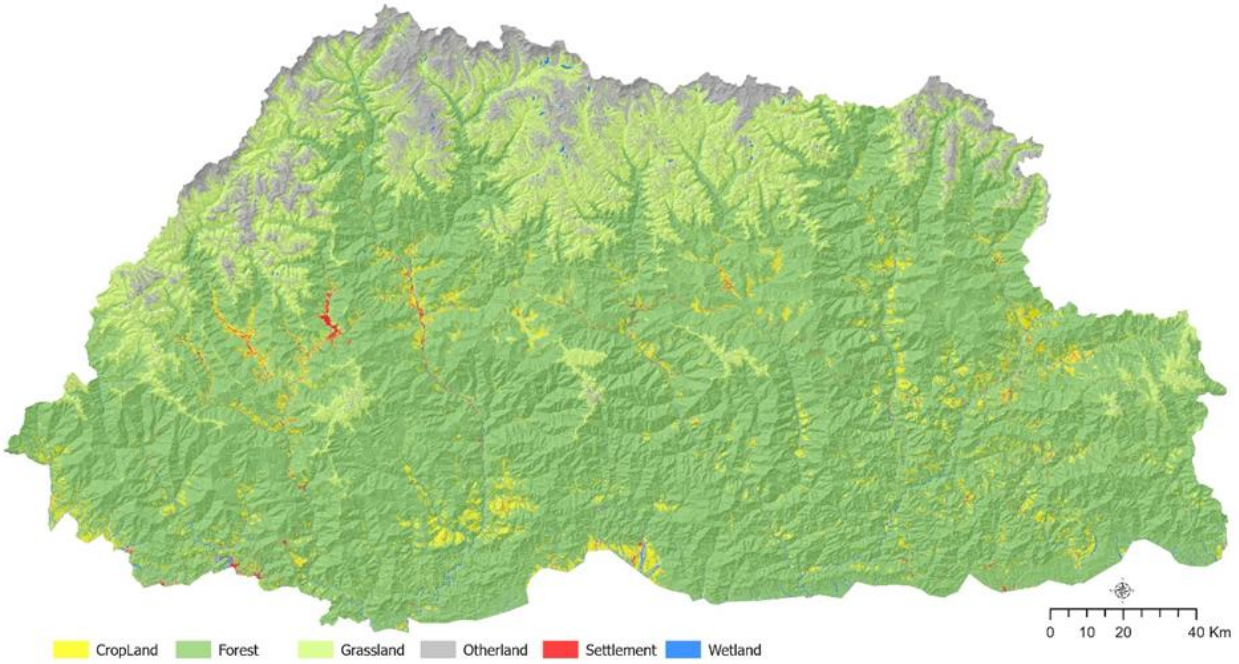


Figure 6: Land Use and Land Cover Map 2017

Table 8: Land Use and Land Cover Classes 2017

Class	Area (ha)	Area (%)
Cropland	114259.14	2.98%
Forest	2702489.15	70.39%
Grassland	707174.86	18.42%
Other land	270170.58	7.04%
Settlement	19700.35	0.51%
Wetland	25605.92	0.67%
Total	3839400.00	100.00%

Table 9: Land Use and Land Cover Map Classes 2023

Class	Area (ha)	Area (%)
Cropland	111791.31	2.91%
Forest	2677896.69	69.75%
Grassland	725607.45	18.90%
Other land	270207.93	7.04%
Settlement	27867.01	0.73%
Wetland	26029.60	0.68%
Total	3839400.00	100.00%

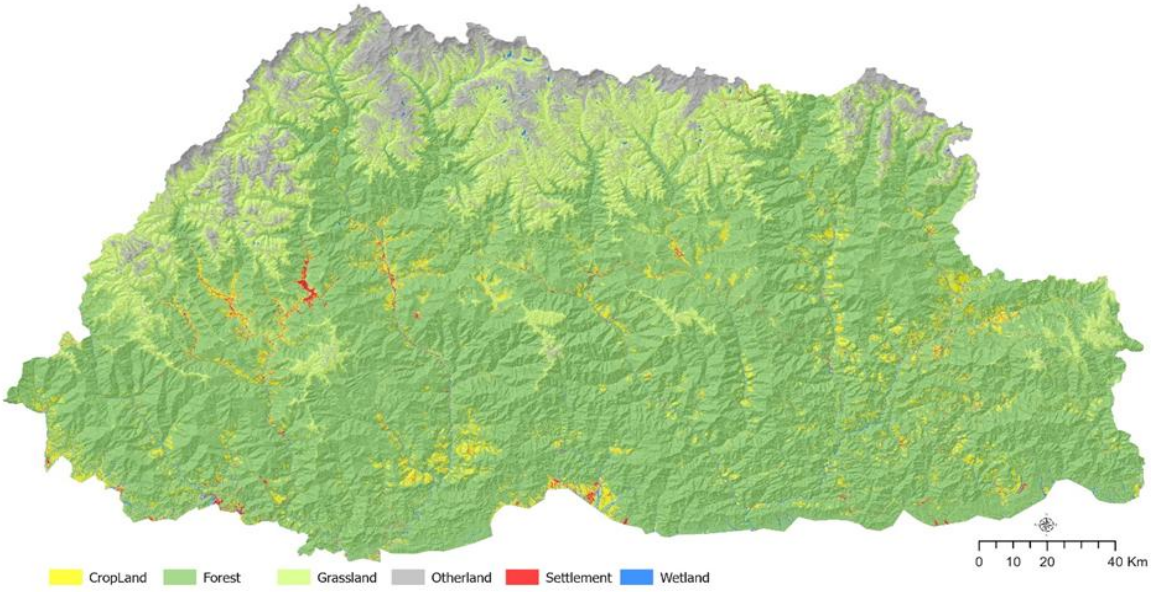


Figure 7: Land Use and Land Cover Map 2023

6.1.2 Land Cover Change

Change analysis was carried out to examine forest dynamic and LULC change during the periods 2015-2017 (Figure 8) and 2017-2023 (Figure 9). The analysis was designed to capture both longer-term trends and recent changes in land cover, with particular emphasis on identifying forest persistence, forest loss and forest gain. By comparing classified maps across these time intervals, the analysis aimed to characterize the spatial extent, distribution, and nature of land-cover transitions.

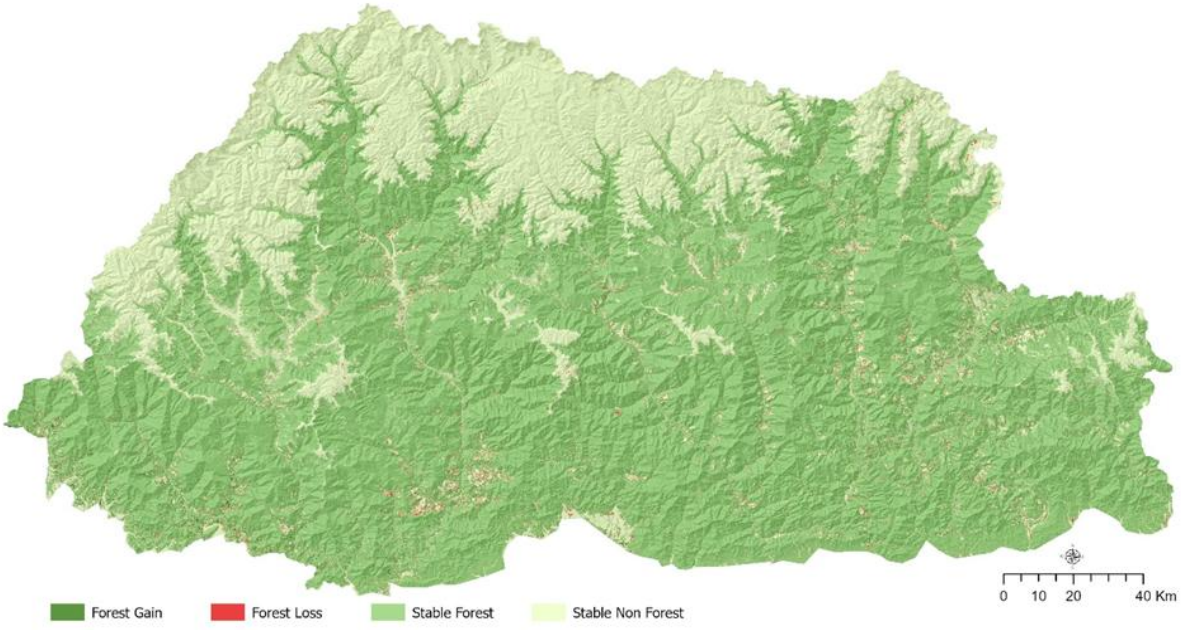


Figure 8: LULC change map of Bhutan (2015-2017)

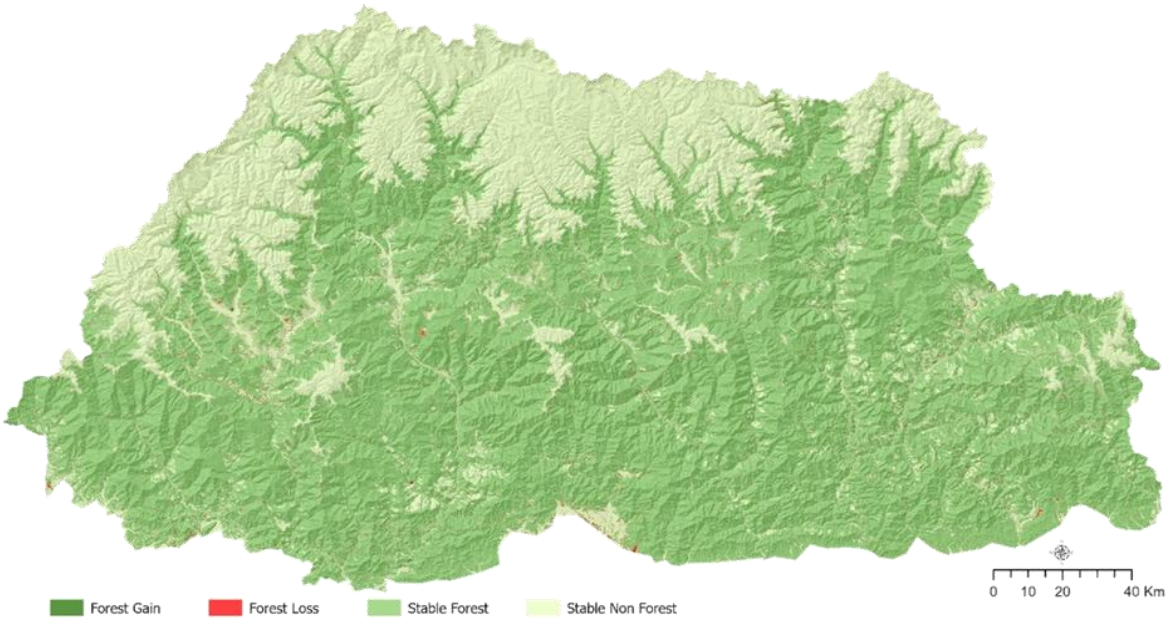


Figure 9: LULC change map of Bhutan (2017-2023)

6.1.2.1 Stratified Area Estimation

Following the change detection analysis between land cover maps, a stratified sample-based area estimation was conducted on the resulting change map to produce statistically unbiased estimates of the area and quantify classification and landcover change uncertainties. The methodology follows the stratified estimation framework proposed by Olofsson et al. (2014), which is designed to address the misclassification errors that commonly affect map-derived statistics. In line with IPCC Good Practice Guidance, this approach helps to reduce systematic bias and supports estimates that are neither over nor underestimates, thereby minimizing the uncertainty. The entire process of stratified area estimation was carried out in SEPAL, a web-based platform developed by Food and Agriculture Organization (FAO).

The sample was designed in STRATIFIED AREA ESTIMATOR-DESIGN tool in SEPAL. This tool helps to generate a set of stratified random samples based on each class or strata of the map. A total of 50 sample points per class were generated for each of the 36 change classes identified on the land cover change map, resulting in 1,800 sampling points. The minimum sample size of 50 per class was determined based on the recommendation of Olofsson et al. (2014), which recommends selecting 50 to 100 samples per stratum to ensure statistically reliable accuracy assessment. To improve the accuracy and precision of the area estimates, the sampling design incorporated a confidence-based classification of strata. Stable land cover classes, such as forest remaining forest, cropland remaining cropland, wetland remaining wetland, etc., were assigned to the high-confidence category, with a user accuracy of 0.9. In contrast, transitional or change classes, such as forest to wetland or cropland to grassland, etc., were assigned to the low-confidence category, with a user accuracy of 0.7. This approach effectively optimizes the sample

allocation, ensuring that high confidence areas receive appropriate representation while directing the additional sampling efforts to areas with lower classification certainty, thereby minimizing potential estimation errors in the final area calculations. The standard error of expected overall accuracy was set to 0.01. A proportional sample allocation was applied; however, within SEPAL, the allocation was automatically adjusted to ensure a minimum of 50 samples per stratum. A plot size of 30 x 30 meters was assigned to each sample point to align with the spatial resolution of Landsat imagery, which was the primary dataset used for map development and change detection.

The sample interpretation was carried out using Collect Earth Desktop (CED). CED is a desktop-based tool developed to support land monitoring, sample-based area estimation, and reference data collection for LULC assessment. It enables users to systematically interpret and classify sample locations using a combination of recent and historical satellite imagery, high-resolution, and auxiliary spatial layers. CED integrates time-series data from Landsat and sentinel along with very high-resolution imagery in Google Earth.

The sampling points were exported from SEPAL platform and imported into CED for reference data collection. At each sample location, land cover interpretation was carried out using high-resolution imagery from Google Earth, complimented by multi-temporal satellite dataset including Sentinel-2, Landsat series (Landsat 5, 7, 8 and 9) along with other ancillary information from MODIS, which are integrated into the CED. These multiple data sources enabled a robust temporal and spatial assessment of land cover conditions, particularly useful for identifying subtle or gradual changes.

The reference data were interpreted and collected by a team of twenty-two trained interpreters. Each interpreter was assigned a subset of sample points. Interpreters followed a consistent and structured classification protocol aligned with the predefined change classes of the study, ensuring accuracy and minimizing subjectivity.

To enhance accuracy and minimize interpreter bias, a rigorous muti-stage interpretation workflow was adopted. Each sample was independently interpreted by two trained interpreters. Both interpreters assessed the reference year and the change trajectory based on available imagery, ensuring independent judgement without influence from the other. This dual interpreter system was designed to reduce individual subjectivity and increase the reliability of the reference dataset.

Following the independent assessments, all samples with conflicting interpretations between the two interpreters underwent a joint reconciliation session. During this stage, both interpreters reviewed the imagery together, discussed the source of disagreement, and reached a consensus based on visual evidence and reference guidelines. This collaborative verification helped standardize decisions and improved overall consistency. For cases, where consensus could not be reached due to complex landcover signatures, ambiguous change patterns, or insufficient visual cues, the sample was escalated for further review by a broader team. These samples were

collectively interpreted by four experts, comprising the original two interpreters and an additional two remote sensing specialists.

Regular coordination and internal checks were conducted to minimize subjective bias and interpretation error. This collaborative approach enabled the systematic collection of high-quality reference data.

Aggregation of Classes

After following the interpretation of reference samples in CED, each of the 36 transition classes was carefully aggregated into four main categories based on the sample interpretations:

Stable forest: All samples where the transitions were from forest to forest were categorized as stable forest. This means that any sample that consistently remained forested over time was placed in this category.

Stable Non-Forest: All samples where the transition remained within non-forest categories were grouped as stable non-forest. This category includes samples that consistently remained non-forest, such as cropland to cropland, grassland to grassland, settlement to settlement, wetland to wetland, and other land to other land, as well as transitions occurring among different non-forest land-cover classes.

Forest Loss: All samples that indicated a transition from forest to non-forest were categorized as forest loss. This includes samples that indicate transitions from forest to cropland, forest to grassland, forest to wetland, forest to settlement and forest to other land. This category captures areas where forest cover was lost over the analysis period.

Forest Gain: All samples that indicated a transition from non-forest to forest, such as cropland to forest, grassland to forest, settlement to forest, wetland to forest and other land to forest were grouped under forest gain. This category captures areas where new forest cover was established during the analysis period.

This aggregation process not only serves to streamline the complexity of the detailed transition matrix but also plays a critical role in mitigating classification uncertainties and reducing potential errors.

6.1.2.2 Sample Analysis

Following the interpretation workflow, all samples were consolidated. This consolidated reference dataset forms the basis for both accuracy assessment and stratified area estimation, ensuring statistical rigor in the quantification of land cover transition. The analysis was carried out using the STRATIFIED AREA ESTIMATOR-ANALYSIS tool available in the SEPAL platform. This tool is designed to produce statistically valid area estimates by combining the mapped strata with

the interpreted reference data. The analysis is performed by linking the interpreted land cover transition for each sample point to the corresponding mapped strata derived from the change map. The mapped area, or the total area assigned to each class in the change map was used as input to ensure that each class was appropriately weighted in the estimation process. The estimator applies the Olofsson et al. (2014) methodology for stratified random sampling, which calculates unbiased area estimates for each transition class by adjusting the mapped area according to the accuracy of the reference data. The tool also computes the standard error, confidence interval, and user's and producer's accuracy of the changed map, allowing for a transparent assessment of the classification uncertainty. This process ensures that the reported areas are statistically sound and account for errors present in the initial map-based classification, ultimately improving the reliability of land cover change estimates. The stratified area estimation was estimated at the confidence interval of 95% in SEPAL.

Further, to estimate the specific transition within the broader land cover change categories, the reference samples representing each transition class were analyzed to identify the actual land cover types involved. For each transition, the total area estimate was proportionally distributed across the detailed sub-categories based on the observed frequency of sample points within each subclass. The reference samples representing broader transitions, such as forest loss or forest gain, were reviewed to determine the specific land cover classes into which the forest had transitioned, or from which the forest had been gained. The area for each sub-category was then computed by applying the proportional distribution of sample points, ensuring that the final area estimates for each transition class reflected the specific land cover types involved. This method allows for a more granular and accurate estimation of land cover transitions, while maintaining the statistical validity of the broader stratified area estimates. Table 10, 11, 12 and 13 shows the stratified area of forest change and conversion of forest to non-forest lands.

Table 10: Stratified Area Based on Land Use Change Analysis (2015-2017)

Class	Map Area (ha)	Stratified Area Estimate (ha)	SE %	Standard Error (ha)	SE %	Confidence Interval (ha)	CI %
Forest Gain	38040.97	760.82	0.02%	377.53	49.62%	739.96	97.26%
Forest Loss	40954.78	4882.81	0.13%	1655.46	33.90%	3244.69	66.45%
Stable Forest	2664448.18	2703127.58	70.40%	3845.30	0.14%	7536.78	0.28%
Stable Non-Forest	1095956.07	1130628.79	29.45%	4153.31	0.37%	8140.48	0.72%
Total	3839400.00	3839400.00					

Table 11: Forest Converted to Non-Forest Land Categories (2015-2017)

Class	Sample	Proportion	Forest Loss (ha)	SE (ha)	SE %	CI (ha)	CI %
Forest to Cropland	2	14.29%	697.54	236.49	33.90%	463.53	66.45%

Forest to Other land	5	35.71%	1743.86	591.23	33.90%	1158.82	66.45%
Forest to Settlement	7	50.00%	2441.4	827.73	33.90%	1622.35	66.45%
Total	14	100.00%	4882.81	1655.56	33.90%	3244.69	66.45%

Table 12:Stratified Area Based on Land Use Change Analysis (2017-2023)

Class	Map Area (ha)	Stratified Area Estimate (ha)	Area %	Standard Error (ha)	SE %	Confidence Interval (ha)	CI %
Stable Forest	2676271.33	2679755.94	69.80%	53947.24	2.01%	105736.58	3.95%
Forest Gain	1625.36	10205.91	0.27%	3002.11	29.42%	5884.14	57.65%
Forest Loss	26217.82	13598.25	0.35%	2929.60	21.54%	5742.01	42.23%
Stable Non-Forest	1135285.49	1135839.90	29.58%	54092.39	4.76%	106021.08	9.33%
Total	3839400.00	3839400.00	100.00%				

Table 13: Forest Converted to Non-Forest Land Categories (2017-2023)

Class	Sample	Proportion	Forest Loss (ha)	SE (ha)	SE %	CI (ha)	CI %
Forest to Cropland	1	1.85%	251.82	54.25	21.54%	106.33	42.23%
Forest to Grassland	4	7.41%	1007.28	217.01	21.54%	425.33	42.23%
Forest to Other land	32	59.26%	8058.22	1736.06	21.54%	3402.67	42.23%
Forest to Settlement	17	31.48%	4280.93	1807.67	21.54%	1807.67	42.23%
Total	54	100%	13598.25	2929.60	21.54%	5742.01	42.23%

The estimated deforested area is estimated by the change maps and stratified area estimation is annualized for each period. The deforestation area for 2015 to 2017 was divided by 2 years (2016 and 2017) based on the image date used in map production. Similarly, the deforested area from 2017 to 2023 was divided by six years (2018, 2019, 2020, 2021, 2022 and 2023). Therefore, the deforestation area is same from 2016 to 2017; and 2018 to 2023 by stratum (CL, GL, SL and OL). Further, for the year 2015, for which the deforestation data was not available, it is assumed to be equal to the annual deforestation area between 2015 and 2017.

6.1.3 Accuracy Assessment

To ensure the reliability of the area estimates derived from the stratified sampling process, accuracy assessment is performed using a confusion matrix within the SEPAL platform The

accuracy assessment is focused on four transition classes. Reference data collected through the visual interpretation in Collect Earth was used to build a confusion matrix and compute associated accuracy metrics within the Stratified Area Estimation Analysis tool. The confusion matrix provides a comparison between the mapped classes and the interpreted reference classes. From this, Producer's accuracy and User's accuracy, and Weighted Producer's accuracy were derived. Table 14 and 15 shows that the confusion matrix and accuracy assessment for 2015-2017 respectively while Table 16 and 17 shows confusion matrix and accuracy assessment for 2017-2023 respectively.

Table 14: Confusion Matrix (2015-2017)

Class	Forest Gain	Forest Loss	Stable Forest	Stable Non-Forest
Forest Gain	4	0	75	121
Forest Loss	0	11	55	134
Stable Forest	0	0	50	0
Stable Non-Forest	0	3	15	1232

Table 15: Producer's accuracy, User's accuracy, and Weighted Producer's accuracy (2015-2017)

Class	Producer's Accuracy	Weighted Producers Accuracy	User's Accuracy
Forest Gain	1.00	1.00	0.02
Forest Loss	0.79	0.46	0.06
Stable Forest	0.26	0.99	1.00
Stable Non-Forest	0.83	0.96	0.99

Table 16: Confusion Matrix (2017-2023)

Class	Forest Gain	Forest Loss	Stable Forest	Stable Non-Forest
Forest Gain	17	1	48	184
Forest Loss	1	43	47	159
Stable Forest	0	0	49	1
Stable Non-Forest	11	10	57	1172

Table 17: Producer's accuracy, User's accuracy, and Weighted Producer's accuracy (2017-2023)

Class	Produce's Accuracy	Weighted Producer's Accuracy	User's accuracy
Forest Gain	0.59	0.01	0.07
Forest Loss	0.80	0.33	0.17
Stable Forest	0.24	0.98	0.98
Stable Non-Forest	0.77	0.94	0.94

6.2 Emission Factors/Removal Factors

EF for deforestation was mainly estimated using methodological guidance provided by the Global Forest Observations Initiative (GFOI) which defines deforestation as the change of forest land to other land category (GFOI, 2016). In IPCC terms, the possibilities of Forest Land replacing land uses are Cropland, Grassland, Wetlands, Settlements or Other Land (GFOI, 2016). The change in biomass/carbon density from forest land to each of the other land categories were estimated using the corresponding methodological guidance available under IPCC latest guidelines 2006GL (IPCC, 2006b). Generally, the following equation was used for estimating the emission factor for each land conversion category.

$$\hat{\mu}_{EF} = \hat{\mu}_B - \hat{\mu}_A \qquad \textit{(Equation 1)}$$

Where, $\hat{\mu}_B$ and $\hat{\mu}_A$represents biomass carbon density for land before conversion and for land after conversion respectively.

The emission of SOC is calculated as difference between SOC density in forest land and forest land converted to corresponding different land categories. In absence of land category specific SOC density for Cropland, Grassland, Settlement and Other Land, the SOC density for new land use category was estimated using IPCC default stock change factor and 20 years transition period (IPCC, 2006b). The soil emission is estimated using the following equation, which is an adaptation of equation 2.25, Chapter 2, Volume 4 of IPCC 2006 (IPCC, 2006b).

$$SOC_{emission} = \frac{SOC_{Forest} - SOC_{non-forest}}{20_{years}} \qquad (Equation\ 2)$$

Emissions from deforestation in the year in question are, therefore, the sum of conversions that occurred in the current year. The carbon density of the forest is obtained from the State of Forest Carbon Report 2023 (Table 19). However, on the recommendation of REDD+ TA, AGB and BGB of trees and sapling were recalculated using the 14 species specific and two general allometric biomass equations.

These data are obtained from the second NFI of Bhutan conducted between July 2021 to June 2022 following the same sampling design, same data collection protocols and data parameters from 2424 permanent cluster plots laid across the country. NFI – I and NFI -II are consistent and future inventories shall follow the same design and data collection parameters.

The emission factors (Table 20) are estimated based on the carbon pool disturbance matrix (Table 18), which assumes that the on deforestation, whole or some part of the carbon pools are lost.

Table 18: Carbon Pool Disturbance Matrix on Deforestation

			Final Land Use			
		Carbon pool	Cropland	Settlement	Otherland	Grassland
Initial Land Use	**Forest Land**	AGB_Trees	Loss	Loss	Loss	Loss
		AGB_Sapling	Loss	Loss	Loss	Loss
		AGB_Shrub	Loss	Loss	Loss	No loss
		AGB_Herb	Loss	Loss	Loss	No loss
		DOM_Litter	Loss	Loss	Loss	Loss
		Soil	Loss over 20 years (difference between SOC in FL and CL)	Loss over 20 years (difference (20% loss on paved surface) between SOC in FL and CL)	Loss over 20 years (difference between SOC in FL and CL)	Loss over 20 years (difference between SOC in FL and CL)
		DOM_CWD	Loss	Loss	Loss	No Loss
		BGB_Root	Loss	Loss	Loss	No loss

Table 19: Carbon Density of Forests

Carbon pools	**Carbon Pool component**	**Biomass (tonnes per ha)**	**MOE %**	**Carbon (tonnes) per hectare**	**MOE%**
Above ground	Tree	270.57	3.66	127.17	4.56
	Sapling	3.18	41.44	1.49	41.53
	Shrub	1.38	21.11	0.65	21.28
	Herb	0.42	24.38	0.20	24.53
BGB	Tree	71.46	12.25	33.59	12.55
	Sapling	1.37	54.81	0.64	54.88
Dead wood	CWD	6.72	11.73	3.16	12.04
Litter	Litter	15.67	13.91	7.36	14.17
Soil	Soil (0-30cm depth)	Forest		68.12	7.44

The carbon density reported in Table 19 is different from the carbon density reported in the NFI Volume II- State of Forest Carbon Report. The carbon density for the REDD+ TA is recalculated using the 14 species specific and two general equations for trees and sapling. Further, the BGB for Tree and sapling roots are estimated using the national average while it is estimated at plot level in the NFI. The decrease in the sapling biomass may be attributed to decrease in the sapling density in the forest between two NFI cycles

Table 20: Emission Factors for Forest Land Converted to Non-Forests Land Categories

Initial land category	Final land Category	Biomass emission factor (t CO_2)	EF SOC (tCO_2)	Total EF (tCO_2)
Forest Land	Cropland	638.95	2.12	641.07
Forest Land	Grassland	498.76	0.37	499.13
Forest Land	Settlement	638.95	2.50	641.45
Forest Land	Otherland	638.95	12.49	651.44

It is assumed that the conversion of forest land to grassland does not result in loss of shrubs, herbs, DOM and BGB carbon pools consistent with the assessed FREL and FRL. Emissions from all carbon pools have been considered for Bhutan's estimated results of FREL and FRL and the estimates of biomass/carbon density are generated from plot level measurements of the NFI of Bhutan.

6.3 Calculation of emission reductions and removal enhancements

The emissions are estimated from deforestations, wood removal and forest fire while removal is estimated by forest remaining forests in sustainable management of forests, conservation of forest carbon stock and enhancement of carbon stock. All calculations are computed following the 2006 IPCC Guidelines, 2019 Refinement of 2006 IPCC Guidelines and GFOI methodological guidance consistent with assessed FREL and FRL.

6.3.1 Estimating Emission from Deforestation

As per GFOI methodological guidance, the total emission from deforestation is estimated by multiplying the forest area converted to non-forest by EF. Table 21 shows the deforestation between 2015 to 2023. It may be noted that the sum of deforestation area reported in Table 11 and 13 is less than the deforestation area reported in Table 21, as the deforestation area for 2015 is extrapolated, and assumed to be equal to deforestation area for 2016 and 2017 in absence of the data.

Emission = Activity Data x Emission Factor *(Equation 3)*

Table 21: Annual Deforestation from 2015 to 2023

Year	CL	GL	SL	OL
2015	348.77	-	1,220.70	871.93
2016	348.77	-	1,220.70	871.93
2017	348.77	-	1,220.70	871.93
2018	41.97	167.88	713.49	1,343.04
2019	41.97	167.88	713.49	1,343.04
2020	41.97	167.88	713.49	1,343.04
2021	41.97	167.88	713.49	1,343.04
2022	41.97	167.88	713.49	1,343.04

2023	41.97	167.88	713.49	1,343.04

6.3.2 Carbon stock change in sustainable management of forests and conservation of forest carbon

The method for estimating carbon stock changes in biomass for sustainable management of forests and conservation of forest carbon stock is based on the gain loss method using equation 2.7, Chapter 2, Volume 4, IPCC 2006

$$\Delta C_B = \Delta C_G - \Delta C_L \qquad (Equation\ 4)$$

Where ΔC_B is annual change in carbon stock in biomass, ΔC_G is the gain through annual increase in carbon stock due to biomass growth, and ΔC_L is the annual decrease in carbon stock due to biomass loss. The carbon pool disturbance matrix on forest land conversion to non-forest land is provided in Annexure I. The emission direct drivers of forest degradation estimated as part of emission from wood removal in sustainable management of forest and conservation of carbon stock while forest fire related emission are estimated as part of SMF. Thus, ensuring consistency with the assessed FREL and FRL.

6.3.2.1 Annual Decrease in Carbon Stock Due to Timber Harvesting

Emissions from timber harvesting is calculated using adapted equation 2.12, Chapter 2, Volume 4, IPCC 2006 with the assumption that there are no changes in BGB.

$$Emission_{Timber} = H \times WD \times BEF \times CF \times 44/12 \qquad (Equation\ 5)$$

Where, $Emission_{Timber}$ is emission from timber harvesting in tCO_2, H is the volume of harvested timber (m^3), WD is wood density (tm^{-3}), CF is carbon fraction of 0.47 and BEF is biomass expansion factor. The BEF of 1.29 and 1.83 used in assed FREL and FRL for conifer and broadleaf timber were used for estimating the emission. Similarly, an average wood density of 0.623 t m^{-3} and 0.483 t m^{-3} for broadleaf and conifer species respectively (UNIDO, 1994) is applied to Equation 8. Table 22 shows the volume of timber removed from SFM and Conservation of forest Carbon stock from 2015 to 2023.

Table 22: Volume of Wood Removals (m^3)

Year	Sustainable management of forests		Conservation of Carbon Stock	
	Broadleaf	Conifer	Broadleaf	Conifer
2015	40179.87	60269.8024	11738.1	17607.1395
2016	81801.33	122701.99	20870.6	31305.84
2017	81487.43	122231.1518	16205.6	24308.4618
2018	43188.18	64782.27876	11414.9	17122.2825

2019	106341.23	159511.84	18315.4	27473.166
2020	35868.44	53802.66	14049.8	21074.766
2021	70851.93	106277.89	11139.3	16708.8998
2022	86144.06	129216.08	11214	16821.03
2023	86708.53	130062.8	14045.1	21067.608
Total	632571	948856.4929	128993	193489.194

6.3.2.2 Non-CO2 Emission from Forest Fire

Non-CO_2 emission from forest fire is included under sustainable management of forests as forest fire doesn't lead to permanent land use change. Non-CO_2 is estimated using adapted Equation 2.27, IPCC 2006, Vol.4, and Chapter 2 as follows:

$$L_{fire} = A \times M_B \times C_f \times G_{ef} \times 10^{-3} \qquad \textit{(Equation 6)}$$

Where,

L_{fire} is the amount of GHG emission from fire tonnes of each GHG (e.g. CH_4, N_2O);
A is the area burnt, ha;
M_B is mass of fuel available for combustion, t/ha;
C_f is combustion factor, dimensionless; and
G_{ef} is emission factor, (g/kg) dry matter burnt.

Forest fire burnt area for reporting period is obtained from annual forest fire statistics maintained by DoFPS. Bhutan collects data on forest fires through the Forest Information Reporting and Monitoring System (FIRMS), an online data repository of the Department of Forests and Park Services as soon as fire events are reported. The data on burned areas is collected by the forestry staff in the field using GPS, post forest fire suppression operation and area figures entered the FIRMS system. M_B is estimated from second NFI data (Table 19) and includes AGB Tree and Saplings in consistent with assessed FREL and FRL. C_f is from Table 2.6 (All "other" temperate forests), and G_{ef} for Extra Tropical forests from Table 2.5 of IPCC 2006. These parameters are applied to Equation 10 to compute emissions from forest fire in individual non-CO_2 gases. These non-CO_2 to CO_2 equivalence was estimated using Global Warming Potential (GWP) Table 8.7, Chapter 8, Anthropogenic and Natural Radiative Forcing, IPCC AR 5 (IPCC, 2014). Table 23 shows areas affected by forest fire, Combustion Factor, Emission Factor and GWP.

Table 23: Fire affected area (ha), Combustion Factor, Emission Factor and GWP

Year	Area affected by fire (ha)		Emission factor			GWP		
		C_f	CO	CH_4	N_2O	CO	CH_4	N_2O
2015	6222.00	0.45	107.00	4.70	0.26	1.80	28.00	265.00
2016	8522.00	0.45	107.00	4.70	0.26	1.80	28.00	265.00

2017	5249.00	0.45	107.00	4.70	0.26	1.80	28.00	265.00
2018	1309.00	0.45	107.00	4.70	0.26	1.80	28.00	265.00
2019	3524.72	0.45	107.00	4.70	0.26	1.80	28.00	265.00
2020	2387.14	0.45	107.00	4.70	0.26	1.80	28.00	265.00
2021	4311.77	0.45	107.00	4.70	0.26	1.80	28.00	265.00
2022	5171.87	0.45	107.00	4.70	0.26	1.80	28.00	265.00
2023	4,070.95	0.45	107.00	4.70	0.26	1.80	28.00	265.00
	40768.45							

6.3.2.3 Annual Increase in Carbon Stock Due to Biomass Growth

The removal (carbon sequestration) is estimated based on the forest area for each year. The removal is calculated using equation 2.9, Chapter 2, Volume 4 of IPCC 2006.

$$Removal_{bgw} = A \times G_{mean} \times CF \times 44/12 \qquad \textit{(Equation 7)}$$

Where, $Removal_{bgw}$ is removal by Forests ($tCO_2\ yr^{-1}$), A is the area of Forests (ha), G_{mean} is mean annual biomass increment ($t\ d.m\ ha^{-1}yr^{-1}$), CF is carbon fraction and 44/12 is CO_2-e fraction. The annual biomass growth of 2.43 t. d.m. $ha^{-1}\ yr^{-1}$ from NFI and carbon fraction of 0.47 is applied to Equation 7. Table 24 shows the area under SFM, Conservation and Plantation.

The A for each year of reporting period is derived through interpolation (FAO, 2018) of forest area using six land use and land cover data sets for the year 1990, 2000, 2010 (Gilani *et al*., 2015) and 2015 (FRMD, 2017), 2017 and 2023 (FMID, 2024) generated from Landsat images. The forest area under conservation includes all forest areas falling within the national parks, wildlife sanctuaries and strict nature reserves; all forest areas outside the conservation is accounted as forest under sustainable forest management except area under plantation, which is considered as land converted to forest land and reported as enhancement for 20 years. The sum of forest area under conservation, sustainable forest management and plantation constitute the total forest area of Bhutan. The plantation is reported as land converted to forest land for 20 years and is transited to SFM from the 21st year considering 20 years transition period as per the 2006 IPCC Guidelines. A substantial increase in forest area under conservation is observed in 2008 compared to previous years. This change is attributed to the declaration of Wangchuck Centennial National Park. Consequently, forest areas that were previously reported under sustainable forest management were reclassified as forests under conservation. Table 24 shows the forest area under different management regimes

Table 24: Forest Area Under Sustainable Forests Management, Conservation of Forest Carbon Stock and Plantations (ha)

Year	Forest Area[5]	Forest Inside Conservation	Forest Outside Conservation	Forest under Plantation	Area under plantation (20 yr. transition/ Cumulative)	Forest Under SFM
1985	2,512,287.00	592,286.70	1,920,000.30	15.17	15.17	1,919,985.13
1986	2,521,101.20	595,370.40	1,925,730.80	473.61	488.79	1,925,242.02
1987	2,529,915.40	598,454.10	1,931,461.30	28.59	517.37	1,930,943.93
1988	2,538,729.60	601,537.80	1,937,191.80	170.93	688.30	1,936,503.50
1989	2,547,543.80	604,621.50	1,942,922.30	721.77	1,410.07	1,941,512.24
1990	2,555,800.00	607,705.20	1,948,094.80	98.00	1,508.07	1,946,586.73
1991	2,564,670.00	610,788.90	1,953,881.10	44.37	1,552.44	1,952,328.67
1992	2,573,540.00	613,872.60	1,959,667.40	66.14	1,618.57	1,958,048.83
1993	2,582,410.00	616,956.30	1,965,453.70	18.36	1,636.93	1,963,816.77
1994	2,591,280.00	620,040.00	1,971,240.00	57.70	1,694.63	1,969,545.38
1995	2,600,150.00	623,123.70	1,977,026.30	152.89	1,847.52	1,975,178.78
1996	2,609,020.00	626,207.40	1,982,812.60	248.86	2,096.38	1,980,716.22
1997	2,617,890.00	629,291.10	1,988,598.90	159.90	2,256.28	1,986,342.63
1998	2,626,760.00	632,374.80	1,994,385.20	45.56	2,301.84	1,992,083.36
1999	2,635,630.00	635,458.50	2,000,171.50	77.18	2,379.02	1,997,792.49
2000	2,644,500.00	638,542.20	2,005,957.80	47.02	2,426.03	2,003,531.77
2001	2,647,370.00	639,342.52	2,008,027.49	92.91	2,518.94	2,005,508.54
2002	2,650,240.00	640,142.83	2,010,097.17	94.88	2,613.83	2,007,483.34
2003	2,653,110.00	640,943.15	2,012,166.85	62.17	2,676.00	2,009,490.85
2004	2,655,980.00	641,743.47	2,014,236.53	112.11	2,788.11	2,011,448.42
2005	2,658,850.00	642,543.79	2,016,306.21	141.31	2,914.24	2,013,391.97
2006	2,661,720.00	643,344.11	2,018,375.89	103.13	2,543.76	2,015,832.13
2007	2,664,590.00	644,144.43	2,020,445.57	109.93	2,625.11	2,017,820.46
2008	2,667,460.00	783,304.76	1,884,155.24	160.60	2,614.78	1,881,540.46
2009	2,670,330.00	784,492.07	1,885,837.93	298.99	2,192.01	1,883,645.93
2010	2,673,200.00	785,679.37	1,887,520.63	238.01	2,332.01	1,885,188.62
2011	2,680,162.08	803,166.26	1,876,995.81	428.18	2,715.82	1,874,279.99
2012	2,687,124.16	820,653.16	1,866,471.00	166.83	2,816.52	1,863,654.48
2013	2,694,086.23	838,140.05	1,855,946.18	161.18	2,959.33	1,852,986.85
2014	2,701,048.31	855,626.94	1,845,421.37	18.69	2,920.32	1,842,501.05
2015	2,708,010.39	873,113.84	1,834,896.55	316.22	3,083.65	1,831,812.91
2016	2,703,507.99	866,022.84	1,837,485.15	310.26	3,145.05	1,834,340.10
2017	2,699,005.59	858,931.85	1,840,073.74	351.46	3,336.61	1,836,737.13
2018	2,695,231.93	851,840.86	1,843,391.07	297.00	3,588.05	1,839,803.02
2019	2,691,458.26	850,611.22	1,840,847.04	175.86	3,686.73	1,837,160.31
2020	2,687,684.60	849,381.58	1,838,303.01	115.63	3,755.35	1,834,547.66

[5] The total forest area is sum of column 3, 6 and 7.

2021	2,683,910.93	848,151.95	1,835,758.98	39.38	3,701.81	1,832,057.17
2022	2,680,137.27	846,922.31	1,833,214.96	14.69	3,621.62	1,829,593.33
2023	2,676,363.60	845,692.67	1,830,670.93	117.96	3,677.41	1,826,993.52

6.3.2.4 Removal from Enhancement of Forest Carbon Stock

Plantations require certain time to establish as forests. The default transition period, prescribed by IPCC (2006), of 20 years was used. The annual biomass growth rate of 2.43 t d.m. ha^{-1} yr^{-1} derived from NFI data was applied to estimate the CO_2 removal through land converted to forest. Equation 8 is used for estimating carbon sequestration from plantations.

$Plantation_{tCO2\text{-}e}$ = (Age of plantation (yr) x Biomass growth (t d.m $ha^{-1}yr^{-1}$)
x Successful Plantation (ha) x .047 x 44/12) *(Equation 8)*

Plantation area from 1985 to 2023 is provided in Annexure II.

7. Uncertainty Analysis

7.1 Calculation of combined uncertainties

The uncertainty of the FREL and FRL results are computed by error propagation method by combining uncertainty of activity data and emission factors using Equation 9.

$$U_{total} = \sqrt{U_{AD}^2 + U_{EF}^2} \quad \textit{(Equation 9)}$$

Where,

U_{total} is total combined uncertainty (%);
U_{AD} is uncertainty of the activity data (%); and
U_{EF} is uncertainty of the emission factor (%).

Equation 9 was adapted from 2019 refinement of IPCC 2006 guideline, Volume 1, Chapter 3. Further Equation 10 and 11 is applied for combining the uncertainties by addition and multiplication respectively.

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \ldots + U_n^2} \quad \textit{(Equation 10)}$$

Where,

U_{total} is the percentage uncertainty in the product of the quantities (expressed as a percentage); and
U_n is the percentage uncertainties associated with each of the quantities

$$U_{total} = \frac{\sqrt{(U_1 \, x \, X_1)^2 + (U_2 \, x \, X_2)^2 + \cdots + (U_n \, x \, X_n)^2}}{(|X_1 + X_2 + \cdots + X_n|)} \qquad \textit{(Equation 11)}$$

Where,

U_{total} is the percentage uncertainty in the sum of the quantities and expressed as a percentage; and

X_n is quantities to be combined; X_i may be a positive or a negative number; and

U_n is the percentage uncertainties associated with each of the quantities

7.2 Combined Uncertainty of Emissions from Deforestation

The combined uncertainty of the FREL is described in Table 25. The average annual emission from 2015- 2023 is 1,563,891.14 tCO_2-e with uncertainty of 11.11%. It should also be noted that the SOC emission includes lagged emission from the deforestation occurred during the reference period.

Table 25: Uncertainty of FREL (2015-2023)

Emission source or sink	Emission in reporting period (CO2 e)
Deforestation Biomass	1,469,692.16
Deforestation SOC	94,198.99
Total	1,563,891.14
Uncertainty (%)	11.11

7.3 Combined Uncertainty of Net Removals from SFM, Conservation and Enhancement

The combined uncertainty of the net removal is described in Table 26. The total net removal during 2015-2023 is -10,749,822.50 t CO_2-e with uncertainty of 10.33%.

Table 26: Uncertainty of FRL (2015-2023)

Emission source or sink	Emission in reporting period (CO2 e)
Sustainable management of forest -Emission	470,916.83
Conservation of carbon stock- Emission	51,297.66
Sustainable management of forest -Removal	-7,678,866.90
Conservation of carbon stock- Removal	-3,578,468.35
Enhancement	-14,701.75
Total	-10,749,822.50
Uncertainty (%)	10.33

The uncertainty for the volume of timber removed, forest area damaged by fire and plantation area are obtained by expert judgement (Annexure IV) following the procedure described by Hemming et al., 2018a; 2006 IPCC Guidelines; Hemming *et al*., 2018b; and, Protocol, G.H.G, 2003. The

detail calculation of uncertainty for activity data and emission factors and their combination uncertainty is provided in Annexure III.

8. Description of how the elements in decision 4/CP.15 Para 1(c) and (d) have considered

8.1 Use of the most recent IPCC Guidance and Guidelines

Bhutan employed the Gain-Loss Method (Equation 2.5, Chapter 2, Volume 4, 2006 IPCC Guidelines for National Greenhouse Gas Inventories) to calculate annual net changes in carbon stocks. The carbon stocks changes are estimated as (1) changes due to reduction of carbon stocks attributed to deforestation; and (2) changes due to conservation, SMF and enhancement of carbon stocks. In addition, wall to wall maps of forest as well as ground-based inventories were consistent with the 2006 IPCC Guidelines.

For the estimation of the enhancement of the carbon stock from the plantation, the growth rate for the natural forest based on the 2nd NFI was used. This provides conservative estimates compared to the 2019 IPPC refinement of the guidelines and non-CO_2 emissions are converted into CO_2 equivalent.

8.2 To establish, according to national circumstances and capabilities, robust and transparent national forest monitoring systems and, if appropriate, sub-national systems as part of national monitoring systems that:

8.2.1 Use a combination of remote sensing and ground-based forest carbon inventory approaches for estimating as appropriate, anthropogenic forest-related greenhouse gas emissions by sources and removals by sinks, forest carbon stocks and forest area changes.

The activity data used in the assessed FREL were generated using both national and global land-cover datasets, while the assessed FRL was developed using national land-cover maps in combination with ground-based NFI data and national statistics produced by the DoFPS. Similarly, the results presented in this Technical Annex were derived using national land-cover data developed under NFMS.

The NFMS comprises both offline and online data management systems that provide spatial forest data, summary reports, and statistical information. The existing NFMS offers comprehensive and up-to-date information on forest resources, including national forest and land-cover datasets, statistics on forest plantations, forest areas affected by fire, and wood removals. These statistics are updated annually and published online, while land-cover datasets are updated periodically using transparent, accurate, and credible methodologies.

The NFMS (https://www.bhutan-nfms.org), SDSS (https://sdss.dofps.gov.bt/) and the FIRMS (https://firms.dofps.gov.bt/) can be accessed online. However, these domains are currently not accessible to public, but data made available on request. Further the data are made publicly

accessible through DoFPS (www.dofps.gov.bt) and the Bhutan NSDI (https://nsdi.systems.gov.bt/) websites.

Under the REDD+ programme, Bhutan prioritizes reducing deforestation, promoting sustainable forest management, conserving forest carbon stocks, and enhancing carbon stocks. Although forest degradation is not addressed directly, its key drivers—such as forest fires and wood removals—are accounted for within the monitoring framework.

For the development of emission factors, Bhutan primarily used NFI, which covers the entire country and 2006 IPCC Guidelines. These NFI data are incorporated into the NFMS and serve as the primary source for emission factors. Reports on forest carbon densities and carbon stocks are published online and made publicly accessible.

8.2.2. Provide estimates that are transparent, consistent, as far as possible accurate, and that reduce uncertainties, taking into account national capabilities and capacities.

The modalities for accessing information sufficient to recalculate REDD+ results are described in Section 6 on Necessary Information to Allow for the Reconstruction of the Results). Accordingly, the estimates presented in this document are considered transparent. Section 4 demonstrates that the methodologies used to produce the results are consistent with those used to establish the FREL/FRL and explains how the REDD+ results are consistent with Bhutan's revised FREL/FRL submission.

To reduce uncertainties, stratified area estimation and accuracy assessment of maps and change maps were performed. Further uncertainty analysis of activities data and emission factor as well as combined uncertainty were performed using the 2006 IPCC Guidelines.

8.2.3 Are transparent and their results are available and suitable for review as agreed by the Conference of the Parties.

Section 6 provides information to allow for the reconstruction of the results including the information on the calculation of activity data and emission factors/removal factors. It also explains how the necessary information for reconstructing the REDD+ results is made accessible, ensuring transparency and suitability for technical review. Further, if required all excel working sheets shall be shared with the review team.

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Annexures

Annexure I: Land Use Change and Carbon Pool Disturbance Matrix

The carbon transfer matrix is developed to estimate the emission factor when the forest land is converted into a new land use category. The table below shows the changes in the carbon pools when forest land is converted to Cropland, Grassland, Wetland and Other land. As result of these changes, the emission factors are different when forest land is converted to new land use category.

			Final Land Use				
		Carbon pool	Cropland	Wetland	Settlement	Otherland	Grassland
Initial Land Use	**Forest Land**	AGB_Trees	Loss	Loss	Loss	Loss	Loss
		AGB_Sapling	Loss	Loss	Loss	Loss	Loss
		AGB_Shrub	Loss	Loss	Loss	Loss	No loss
		AGB_Herb	Loss	Loss	Loss	Loss	No loss
		DOM_Litter	Loss	Loss	Loss	Loss	Loss
		Soil	Loss over 20 years (difference between SOC in FL and CL)	Loss/Gained over 20 years (difference between SOC in FL and CL)	Loss over 20 years (difference (20% loss on paved surface) between SOC in FL and CL)	Loss over 20 years (difference between SOC in FL and CL)	Loss over 20 years (difference between SOC in FL and CL)
		DOM_CWD	Loss	Loss	Loss	Loss	No Loss
		BGB_Root	Loss	Loss	Loss	Loss	No loss

Annexure II: Plantation Area from 1985 to 2023 used for Estimating Enhancement of Carbon.

The area of plantation is obtained from the record maintained by DoFPS from 1985 to 2023 for estimation of carbon enhancement. The enhancement is calculated as land converted to forest land over 20 years transition period as per IPCC 2006.

SN	Year	Area Planted (ha)	Area survived (ha)	SN	Year	Area Planted (ha)	Area survived (ha)
1	1985	75.2635	15.1708	21	2005	337.743	141.307
2	1986	837.222	473.615	22	2006	207.434	103.133
3	1987	112.79	28.5854	23	2007	203.12	109.934
4	1988	554.675	170.929	24	2008	272.827	160.6
5	1989	1322.74	721.766	25	2009	618.583	298.993
6	1990	639.125	98.0035	26	2010	546.144	238.006
7	1991	799.437	44.3667	27	2011	691.964	428.177
8	1992	293.401	66.1352	28	2012	393.541	166.83
9	1993	195.593	18.3578	29	2013	369.628	161.176
10	1994	243.22	57.6995	30	2014	34.5521	18.687
11	1995	366.403	152.893	31	2015	632.44	316.22
12	1996	516.472	248.859	32	2016	620.51	310.26
13	1997	414.374	159.897	33	2017	702.92	351.46
14	1998	190.886	45.5617	34	2018	594	297
15	1999	199.725	77.1761	35	2019	351.71	175.86
16	2000	235.167	47.0161	36	2020	231.26	115.63
17	2001	212.885	92.9123	37	2021	78.75	39.38
18	2002	232.322	94.8832	38	2022	29.38	14.69
19	2003	145.343	62.1688	39	2023	235.91	117.96
20	2004	213.452	112.111				

Annexure III: Uncertainty Calculation

1. Calculation of Uncertainties

The combined uncertainty of the FREL and FRL is estimated using error propagation method described in 2019 refinement of IPCC 2006 Guidelines, Volume 1, and Chapter 3. The combined uncertainty is estimated using Equation 1.

$$U_{total} = \sqrt{U_{AD}^2 + U_{EF}^2} \qquad Equation\ 1$$

Where,

U_{total} is the total combined uncertainty (%);
U_{AD} is the uncertainty of the activity data (%); and
U_{EF} is the uncertainty of the emission factor (%).

Further Equation 2 and 3 is applied for combining the uncertainties by addition and multiplication respectively.

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \ldots + U_n^2} \qquad \text{(Equation 2)}$$

Where,

U_{total} is the percentage uncertainty in the product of the quantities (expressed as a percentage); and
U_n is the percentage uncertainties associated with each of the quantities.

$$U_{total} = \frac{\sqrt{(U_1 \times X_1)^2 + (U_2 \times X_2)^2 + \cdots + (U_n \times X_n)^2}}{(|X_1 + X_2 + \cdots + X_n|)} \qquad \text{(Equation 3)}$$

Where:

U_{total} is the percentage uncertainty in the sum of the quantities and expressed as a percentage;
X_n is quantities to be combined; xi may be a positive or a negative number; and
U_n is the percentage uncertainties associated with each of the quantities.

2. Uncertainty of Forest Reference Emission Level Results

The combined uncertainty of the deforestation activity data and emission factors is estimated using Equation 3. The combined uncertainty of emission factors for mineral soil (SOC) and non-CO_2 emission factors are calculated using Equation 2 and 3. Table 1, 2 and 3 shows the combined uncertainty of activity data (deforestation), emission factor (biomass) and emission factor (SOC) respectively.

Table 1: Combined uncertainty of deforestation area (2015-2023)

Initial Land Use	Final Land Use	2015-2023 (Deforestation area, ha)	MoE %	Annual Average deforestation (ha)	MoE% (annual)
Forest Land	Cropland	1298.13	31.10	144.24	31.10
Forest Land	Grassland	1007.28	17.24	111.92	17.24
Forest Land	Settlement	7943.03	19.98	882.56	19.98
Forest Land	Other Land	10674.01	16.06	1186.00	16.06
Total		20922.45		2324.72	
Combined uncertainty				2324.72	**11.36**

Table 2: Combined Uncertainty of Emission Factor (biomass carbon)

Carbon Pool component	Carbon (tonnes per ha)	MOE%
Trees_AGB	127.17	4.56
Shrubs_AGB	1.49	41.53
Herbs_AGB	0.65	21.28
Sapling_AGB	0.20	24.53
Tree Roots_BGB	33.59	12.55
Sapling roots_BGB	0.64	54.88
Coarse woody Debris	3.16	12.04
Litter	7.36	14.17
Total	**174.26**	**4.18**

Table 3: Combined Uncertainty of SOC Emission Factor

Land conversion	SOC_{REF}		F_{LU}		F_{MG}		F_I				Change	
	Mean	MOE %	Mean	MOE %	Mean	MOE %	Mean	MOE %	SOC_{after}	MOE %	Difference	MOE %
FL-CL	68.12	7.44	0.83	11	1	0	1	0	56.54	13.28	11.58	7.27
FL-GL	68.12	7.44	1	0	0.97	11	1	0	66.08	13.28	2.04	7.55
FL-SL	68.12	7.44	0.8	5.952	1	0	1	0	54.50	9.53	13.62	5.92
FL-OL	68.12	7.44	0	0	0	0	0	0	0.00	7.44	68.12	7.44
Total									**177.12**	**7.15**	**95.36**	**5.46**

The combined uncertainty of deforestation is described in Table 4. The total annual average emission during 2015 – 2023 is 1,563,891.14 tCO_2-e with uncertainty of 10.09%. The summary of uncertainty of FREL results is presented in Table 5.

Table 4: Uncertainty of Emission from Deforestation During 2015-2023 (Annual)

IPCC Category	Gases	Emissions or removals	AD uncertainty	EF/parameter uncertainty	Combined uncertainty	Contribution to variance by category
		t CO2 e	%	%	%	
					SQRT(E2+F2)	*(GxC)2/(Total C)2*
DEFORESTATION						
Biomass						
FL-CL	**CO2**	92,160.02	31.10	4.18	31.38	3.420
FL-GL	**CO2**	55,821.22	17.24	4.35	17.78	0.403
FL-SL	**CO2**	563,911.00	19.98	4.18	20.41	54.178
FL-OL	**CO2**	757,799.92	16.06	4.18	16.59	64.636
Soil Organic Carbon					0.00	0.000
FL-CL	**CO2**	3,025.98	31.10	7.27	31.94	0.004
FL-GL	**CO2**	399.16	17.24	7.55	18.82	0.000
FL-SL	**CO2**	14,587.21	19.98	5.92	20.84	0.038
FL-OL	**CO2**	76,186.63	16.06	7.44	17.70	0.743
TOTAL		**1,563,891.14**				**123.422**
INVENTORY UNCERTAINTY	**%**					**11.110**

Table 5: Uncertainty Analysis of FREL Results (Annual)

Emission source or sink	Emission in reporting period (CO2 e)
	2015-2023
Deforestation Biomass	1,469,692.16
Deforestation SOC	94,198.99
Total	1,563,891.14
Uncertainty (%)	11.11

3. Uncertainty of Forest Reference Level Results

The FRL results is estimated taking into consideration the area under sustainable management of forests, conservation of forest carbon stock and enhancement of carbon stock and associated emissions from each of these REDD+ activities.

Data for timber harvesting, forest fires and plantation were obtained from the record maintained by DoFPS and uncertainty information for these data are not available. Therefore, a semi-structured expert judgement for assessment of the uncertainty was conducted for each of these

activities. According to the expert judgement analysis, the uncertainty was 20% each for wood removal, forest area damaged by fire and successful plantation area respectively.

The area under conservation of carbon stock and sustainable management of forests is obtained by interpolation of LULC data of 1990, 2000, 2010 (Gilani *et al*., 2015), LULC map of Bhutan 2015 (FRMD, 2017), 2017 and 2023 LULC maps (FMID, 2024)). The overall accuracy of the 2010 land cover map is 83% and same level of accuracy is applied to land use map of 1990 and 2000. The overall accuracy of 2015 LULC map is 98%, 2017 map is 91% and 2023 map is 90%. Therefore, due to lack of disaggregated information on uncertainty for LULC, an error of 17% was applied to 1990, 2000 and 2010; and error from the stratified area estimation for year 2015,2017 and 2023 are used. The combined uncertainty of forest area was computed by taking average of the uncertainty of four LULC maps as neither Equation 2 nor 3 can be applied (Table 6). This average uncertainty is considered as activity data uncertainty for computing the sequestration from SMF and Conservation of Carbon Stock.

Table 6: Uncertainty of Forest Area

Year	Forest Area	Accuracy %	MoE%	
1900	2,555,800.00	83%	17	
2000	2,644,500.00	83%	17	
2010	2,673,200.00	83%	17	
	For year 2015, 2017 and 2023, area and error is based in stratified area estimation			
2015	2,708,010.39	98%	0.303	Based on stratified area
2017	2,699,005.59	91%	0.305	Based on stratified area
2023	2,676,363.60	90%	3.963	Based on stratified area

The annual biomass increment of forest remaining forest is 2.43 ±0.24 t ha^{-1}, which is 9.8% margin of error and is applied as uncertainty for the removal factor. The uncertainty of emission factor for non-CO2 emission from forest fire is described in Table 7. The uncertainty for wood density and biomass expansion factor is computed and applied as emission factor uncertainty for wood removals from SMF and conservation of carbon stock. Table 8 shows uncertainty of biomass conversion and expansion factors (BCEF).

Table 7: Emission Factor Uncertainty of Non-CO2 Emission From Forest Fire

Gases	M_B		C_f		G_{ef}		
	Mean	MOE%	Mean	MOE%	Mean	MOE%	Combined Uncertainty(%)
CO	273.75	3.75	0.45	39.200	107	67.776	78.385
CH_4	273.75	3.75	0.45	39.200	4.7	79.234	88.48
N_2O	273.75	3.75	0.45	39.200	0.26	52.769	65.843

Table 8: Uncertainty of BCEF X CF

Sl.No.	Timber type	BEF	MoE%	WD (t m^{-3})	MoE%	CF	MoE%	BCEF XCF	MoE%
1	Conifer	1.292	89.009	0.483	8.075	0.47	2.71	0.29	89.42
2	Broadleaf	1.830	121.31	0.623	6.260	0.47	2.71	0.54	121.50
3	Forest	1.561	80.082	0.553	4.987			**0.415**	**84.654**

The combined uncertainty of the SFM, Conservation and plantation is described in Table 9. The average annual net removal during 2015 to 2023 is 10,749,822.50 t CO_2-e with uncertainty of 10.326%. Table 10 shows the summary of uncertainty of FRL results

Table 9: Uncertainty of Emission and Removals from SFM, Conservation and Plantations for 2015-2023 (Annual)

IPCC Category	**Gases**	**Emissions or removals**	**AD uncertainty**	**EF/parameter uncertainty**	**Combined uncertainty**	**Contribution to variance by category**
		t CO_2 e	**%**	**%**	**%**	
					$SQRT(E^2+F^2)$	$(GxC)^2/(TotalC)^2$
Sustainable Management of Forest						
Wood Removals - Broadleaf	**CO_2**	138,143.42	10.00	121.50	121.914	2.454
Wood Removals - Conifer	**CO_2**	113,416.48	10.00	89.42	89.973	0.901
Forest Fire - CO	**CO**	107,474.29	10.00	78.39	79.020	0.624
Forest Fire - CH4	**CH_4**	73,435.18	10.00	88.48	89.043	0.370
Forest Fire - N2O	**N_2O**	38,447.47	10.00	65.84	66.598	0.057
Conservation of Forest Carbon Stock						
Wood Removals - Broadleaf	**CO_2**	28,169.97	10.00	121.50	121.914	0.102
Wood Removals - Conifer	**CO_2**	23,127.69	10.00	89.42	89.973	0.037
Sustainable Management of Forest						
Forest growth	**CO_2**	(7,678,866.90)	7.71	10.24	12.820	83.869
Conservation of Forest Carbon Stock						
Forest growth	**CO_2**	(3,578,468.35)	7.71	10.24	12.820	18.214
Enhancement of carbon stock						
Plantation growth	**CO_2**	(14,701.75)	20.00	10.24	22.470	0.001
TOTAL		**(10,749,822.50)**				**106.629**
INVENTORY UNCERTAINTY	**%**					**10.326**

Table 10: Uncertainty of FRL Results

Emission source or sink	Emission in reporting period (CO2 e)
	2015-2023
Sustainable management of forest -Emission	470,916.83
Conservation of carbon stock- Emission	51,297.66
Sustainable management of forest -Removal	-7,678,866.90
Conservation of carbon stock- Removal	-3,578,468.35
Enhancement	-14,701.75
Total	-10,749,822.50
Uncertainty (%)	10.33

Annexure IV: Expert Judgement for Assessment of Uncertainty

1. Description of the Problem

The volume of wood removed is used as activity data to estimate the emission from Sustainable management of forest and Conservation of Carbon Stock. The statistical records of wood removed from Sustainable management of forest and conservation area are available through annual publication of Department of Forests and Park Services, while the uncertainty of the volume of wood removed is not available. The best assumption of error with these statistics is to consider that the data is 100% correct. However, the likelihood of either double counting or under reporting of the actual volume of wood removed cannot be ignored.

Similarly, substantial areas of forests are damaged by forest fire annually. The assessment of the forest burnt or damaged by the forest fires is done using GPS mapping where possible and is reported by field offices. DoFPS produces the annual statistics of the forest area damaged by forest fire. However, there is no system in place to assess accurateness of fire burnt forest area reported and published, as well are subject to human error.

In addition, DoFPS has been carrying out forest plantation annually since 1950s. However, no spatial mapping of the plantations was carried out in the past and spatially explicit records are not available. Therefore, it is difficult to ascertain where and how many plantations are successfully converted into forests. Plantation monitoring carried out by Social Forestry and Extension Division (SFED) of DoFPS shows an average survival percentage of 50%. Therefore, 50% of the total planted area is used as an activity data for estimation of enhancement from plantation.

2. Parameters for which the uncertainty values are needed

1. Uncertainty of volume of wood removed
2. Forest area damaged by fire
3. Forest area brought under plantation

3. List of Experts

43 experts were identified for uncertainty assessment for volume of wood removed from forest, area of forest damaged by forest fires and plantation area survival percentage reported by DoFPS in annual forestry facts and figure.

1. Chief Forestry Officers (19 Field Offices)
2. Data Manager (24 Field Offices)

4. Expert Elicitation Questions

4.1 Wood Removal

All field offices under Department of Forests and Park Services report volume of timber allotted for various purposes through FIRMS and FMID publish this data annually in annual forestry statistics. The experts were asked to rate the confidence on volume of wood reported in Annual Forestry Statistics on the scale of 1-10, 1 being low confidence and 10 being high confidence.

4.2 Forest Damaged by Fire

All field offices under Department of Forests and Park Services report forest area damaged due to forest fire through FIRMS which are also published annually in annual forestry statistics by FMID. The experts were asked to rate the confidence on forests damaged by fire and reported in Annual Forestry Statistics on the scale of 1-10, 1 being low confidence and 10 being high confidence.

4.3 Plantation

All field offices under Department of Forest and Park Services report area of land brought under plantation through FIRMS and FMID publish this data annually in annual forestry statistics. The experts were asked to rate the confidence on area of plantation carried out and reported in Annual Forestry Statistics on the scale of 1-10, 1 being low confidence and 10 being high confidence.

5. Aggregation of Uncertainties

5.1 Weighing Expert Judgement

The data used for wood removal, area damaged by forest fire and plantation area were based on actual record with the Department. However, the potential omission and duplication at the time of data entry and reporting cannot be ignored. Therefore, estimation of uncertainty associated with these parameters was done using expert judgement as part of the post hoc analysis. The confidence scale of 1-10 are converted into scores of 1 to 10 points and computed mean confidence score (rounded to nearest whole number) and assigned a percentage uncertainty for each of the parameters based on Table 1.

Table 1: Average Confidence Score and Uncertainty Percent

Average confidence score	10	9	8	7	6	5	4	3	2	1
Error percent	0	10	20	30	40	50	60	70	80	90

The uncertainty of each of the parameters identified above are assigned based on the average confidence score of the experts. It was assumed that no data is 100% correct and there are some forms of errors associated with it.

5.2 Result of Expert Judgement

Based on the weights assigned to each expert in the previous section and the uncertainty of the volume of wood removed, forest areas burnt by fire and area of successful plantation are described in Table 2.

Table 2: Uncertainty of Wood Removals, Forest Fire Damage and Plantation

Parameter	Average confidence score	Uncertainty (%)
Volume of wood removed	8.8 ≈ 9	10
Forest area damaged by fire	8.70 ≈ **9**	10
Successful forest plantation	8.4 ≈ 8	20





Forest Monitoring and Information Division
Department of Forests and Park Services
Ministry of Energy and Natural Resource
Royal Government of Bhutan