The Republic of Zimbabwe

Ministry of Environment, Climate, and Wildlife

Forest Reference Emission Level Submission to the UNFCCC

June 2024

Foreword

Zimbabwe has been continuously demonstrating her willingness to preserve the global climate for the good of the present and future generations. The country submitted Intended Nationally Determined Contribution (INDC) in 2015 which became the first NDC in 2017 when the country ratified the Paris Agreement. In 2021 Zimbabwe presented a revised Nationally Determined Contribution (NDC) which reported a 7% increase in emission reduction from 33% in the first NDC to 40% in this revised NDC. The forestry sector has been identified as one of the major contributors of Greenhouse Gas emissions in Zimbabwe and the country acknowledges the role of REDD+ in fostering atmospheric carbon sequestration and provision of alternative livelihoods to communities heavily dependent on forests.

At the moment, Zimbabwe is in the process of developing the relevant tools and documents required for REDD+ activities implementation, one of which is her first ever Forest Reference Emission Level (FREL). Having an assessed FREL in place is one of the requirements to be eligible for results-based payments in accordance with decision 9/CP.19. Developing countries aiming to implement REDD+ activities are invited to submit their FRELs to the secretariat, voluntarily, in a transparent manner, consistent with greenhouse gas inventory estimates and the guidance agreed upon by the Conference of Parties (CoP).

Zimbabwe has, therefore, developed her first FREL as the first of several upcoming iterations in a stepwise approach that will incorporate better data, improved methodologies, new knowledge, and new trends with time. Thus, the current FREL is not intended to prejudge Zimbabwe's Nationally Determined Contribution or any other mitigation actions but to serve as a benchmark for assessing the country's performance in implementing REDD+ activities.

The submission of this FREL is, therefore, a trendsetter in the country's quest to develop and finalize other REDD+-related documents required for results-based payment programs and carbon markets, including the National REDD+ Strategy (NRS), the Safeguard Information System (SIS), and the National Forest Monitoring System (NFMS) as prescribed by the Warsaw Framework.

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List of Acronyms

AD	Activity Data
AFOLU	Agriculture Forestry and Other Land Use
AGB	Above Ground Biomass
ALOS-PALSAR	Advanced Land Observing Satellite Phased Array L-band Synthetic Aperture Radar
BGB	Below Ground Biomass
CE	Collect Earth
CF	Carbon Fraction
CI	Confidence Interval
CNA	Country Needs Assessment
CO2	Carbon Dioxide
CO2e	Carbon Dioxide equivalent
CoP	Conference of the Parties
DBH	Diameter at breast height
DW	Dead Wood
EF	Emission Factor
EMA	Environmental Management Agency
ETM+	Enhanced Thematic Mapper Plus
ESA	European Space Agency
FAO	Food and Agriculture Organization of the United Nations
FC	Forestry Commission
FCBM	Forest Cover Benchmark Map
FNC	Fourth National Communication

FRA	Forest Resources Assessment
FREL	Forest Reference Emission Level
FREL	Forest Reference Emission Level
GDP	Gross Domestic Product
GFC	Global Forest Change
GFS	Global Forest Survey
GHG	Green House Gas(es)
GPG	Good Practice Guidance
GLCF	Global Land Cover Facility
Ha	hectare
HRP	Historic Reference Period
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature and Natural Resources.
L	Litter
LCCM	Land Cover Change Mapping
LCCS	Land Cover Classification System
LULC	Land Use-Land Cover
LULCT	Landuse/landcover Change Transition
MRV	Measuring, Reporting, and Verification
NDA	National Designated Authority
NDC	Nationally Determined Contribution
NDVI	Normalized Difference Vegetation Index
NFI	National Forest Inventory
NFMS	National Forest Monitoring System

NICFI	Norway’s International Climate and Forests Initiative
NRS	National REDD+ Strategy
QA	Quality Assurance
QC	Quality Control
REDD+	Reducing Emissions from Deforestation and forest Degradation; and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks.
SDG	Sustainable Development Goals
SEPAL	System for Earth Observation Data Access, Processing, and Analysis for Land Monitoring
SOC	Soil Organic Carbon
SoP	Standard Operating Procedures
tC	Tonnes of Carbon
tCO2e	Tonnes of CO2 equivalent
UNFCCC	United Nations Framework Convention on Climate Change
UN-REDD	The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation

Executive Summary

Zimbabwe is a medium forest cover country, with a naturally regenerating forest area of approximately 13.6 m Ha, which is about 35 % of the country's total land area. The deforestation rate assessed over a historic reference period of 2016-2021 has been estimated at 39,449.2 Ha per year, or 0.3 % of forest cover lost annually. The country has initiated a stepwise approach in developing and submitting her FREL. This FREL submission is the first stage of such a stepwise approach and aims at providing an objective benchmark that enhances the country's capacity to assess the performance of REDD+ activities countrywide.

The building blocks for this FREL are summarized below:

- Forest definition: an area of more than 0.5 Ha extent with more than 10 % canopy cover from trees that are or capable of exceeding 5 m in height,
- Scale: National,
- Activities: Only deforestation is reported,
- Deforestation definition: the conversion of natural forest land to non-forest land. This excludes planned felling of plantation forests whether temporarily or permanently,
- Gases: Only CO_2 is covered,
- Pools: Aboveground biomass (ABG) and Belowground biomass (BGB),
- Emission Factors: Based on the National Forest Inventory (NFI) program data collected between 2017 and 2023 in combination with tier 1 data from IPCC Good Practice Guidance 2006 tables, refined in 2019,
- Historic Reference period: 2016-2021 (inclusive),
- Calculation Approach: Historical average of emissions associated with deforestation during the historic reference period,
- Validity period: 2022 - 2027 (inclusive).

The national scale FREL for the deforestation REDD+ activity has been estimated at **5,187,697.6 tCO_2e/ year** with a propagated uncertainty of **1,573,976.3 tCO_2e**, which is 30.3 % at the 95 % confidence interval. Future areas of improvement have been identified as: addition of more pools, addition of more REDD+ activities, addition of removals, further refinement of the NFI program and landcover mapping process to facilitate forest stratification and sampling of all land use classes, and overall strengthening of technical capacity.

1. Introduction

1.1.Background and context

Zimbabwe is renowned for its scenic landscapes comprising mosaics of vegetation types that provide critical wildlife habitat. About 75% of the country is semi-arid and experiences low and erratic rainfall. The forest sector contributes approximately 4 % of the country's GDP, with about 5.3 million people, largely in rural areas, dependent on forestry resources for their livelihoods[1]. As such, forests are vulnerable to land conversion activities: mainly slash and burn shifting cultivation, extraction of wood products for domestic energy (firewood) and construction, unsustainable commercial exploitation of indigenous wood products, unsustainable grazing practices, and wildfires. The Agriculture Forest and Other Land Use (AFOLU) sector has been the largest contributor to GHG emissions in Zimbabwe accounting for 54 % of GHG emissions as of 2017[2]. The ever-increasing demand for land for agriculture and settlement expansion, coupled with degrading agricultural soils constantly creates pressure on remnant forests. Furthermore, the expanding and intensifying construction activities in the country and international demand for valuable timber species existing in the country such as teak (*Baikiaea plurijuga*) and mahogany (*Afzelia quanzensis)* have contributed to illegal harvesting leading to forest degradation. As one of the world's biggest tobacco-farming countries in the world, the demand for tobacco-curing firewood has traditionally been a major cause of deforestation.

Zimbabwe has witnessed success in several economic and social development projects in the 21st century. Inevitably, such development comes in tandem with GHG emissions-related challenges. Despite the successful rural electrification program in the 21st century, the electricity is mainly supplied by the Kariba hydropower station, and thus, low rainfall patterns in recent years, among other factors, have resulted in a shortage of electricity and subsequently an increase in the consumption of fuelwood as the most accessible alternative energy source which therefore

[1] Zimbabwe National Climate Policy, 2017
[2] https://unfccc.int/sites/default/files/NDC/2022-06/Zimbabwe%20Revised%20Nationally%20Determined%20Contribution%202021%20Final.pdf

has contributed to the increased forest loss of late. Additional factors driving land use change include late hot-season bushfires, mining, and overall infrastructure development.

1.2.REDD+ Progress in Zimbabwe

The Government of Zimbabwe identified REDD+ as a critical mechanism in fostering atmospheric carbon sequestration and provision of alternative livelihoods to communities heavily dependent on forests. In 2013, Zimbabwe submitted a country-level REDD+ country needs assessment (CNA) report to the UN-REDD programme as part of the preparation for REDD+ and the associated Monitoring, Reporting, and Verification (MRV). The CNA focused on the identification of national and sub-national stakeholders and their various roles in REDD+ issues as well as gaps and capacity development needs in institutional roles and mandates regarding REDD+. The CNA noted two critical impediments to the development of REDD+ in Zimbabwe as (1) lack of finance and (2) lack of technical capacity.

Zimbabwe has got several policies and strategies that regulate natural resources utilization and stewardship. A list of applicable new and old polices and strategies that are related to GHG accounting and reporting are listed in Table 1.1. However, despite joining the UN-REDD programme in 2013 and the efforts henceforth to strengthen her policies and legislative framework to enhance climate action, the country still hasn't complied with the Warsaw Framework for REDD+ and faces several challenges and remaining gaps, one of which is the nonexistence of critical national REDD program documents such as FRELs, REDD+ strategy, National Forest Monitoring System, and a Safeguard Information System.

Table 1.1. Policies and strategies developed to safeguard natural resources in Zimbabwe.

Instrument (Policy/Legislation)	**Scope**
Forest Act Chapter 19:05 of 1986	Legislation governing the sustainable management, conservation, and utilization of forests, including provisions for forest protection and management planning.
Communal Land Forest Produce Act Chapter 19:04 of 1988	Regulates the harvesting and utilization of forest products in communal lands, aiming to ensure sustainable use and equitable benefit-sharing from forest resources.
Environmental Management Act Chapter 20:27 of 2002	Comprehensive legislation governing environmental protection, conservation, and sustainable management in Zimbabwe.
Parks and Wildlife Act Chap [20:14] of 1975	Legislation governing the management and conservation of national parks, reserves, and wildlife in Zimbabwe, including provisions for protecting forest habitats and biodiversity.
Communal Land Act Chapter 20:04 of 1983	Governs land ownership, use, and management in communal areas. The Act recognizes communal ownership of land by communities, outlines rules for land allocation and management, and emphasizes the importance of community participation in decision-making processes

Instrument (Policy/Legislation)	Scope
Rural District Council Act (Chapter 29:13) of 1988	Empowers Rural District Councils (RDCs) in Zimbabwe to establish bylaws related to the environment within their respective jurisdictions. These bylaws allow RDCs to regulate various environmental aspects to ensure sustainable management and protection of natural resources in rural areas
National Environmental Policy of 2006	Sets out the government's objectives and strategies for environmental protection, conservation, and sustainable development.
National Forest Policy of 2024	Outlines strategies for sustainable forest management, conservation, and utilization of forest resources in Zimbabwe.
National Climate Policy of 2016	Addresses climate change mitigation and adaptation, including strategies for reducing greenhouse gas emissions and building resilience.
Zimbabwe Wildlife Policy of 1992	Guides the management and conservation of wildlife resources, including protection of endangered species and biodiversity.
Zimbabwe National Water Policy of 2013	Addresses water resource management, conservation, and allocation, as well as strategies for ensuring equitable access to water.
Environmental Impact Assessment (EIA) SI 7 of 2007	Regulate the assessment of potential environmental impacts of proposed projects and activities, ensuring compliance with environmental standards.

Instrument (Policy/Legislation)	Scope
National Energy Policy of 2019	Promotes the development and utilization of renewable energy sources such as solar, wind, and hydroelectric power in Zimbabwe.
SI 116 of 2012 on Forest Regulations	Control of Firewood, Timber and Forest Produce
Zimbabwe Land Policy	Guides land use planning and management, balancing conservation objectives with agricultural, urban development, and infrastructure needs.
Carbon Trading Framework of 2023	Establishes a framework for trading carbon credits generated from emission reduction projects, potentially providing financial incentives for forest conservation and carbon sequestration initiatives.
National Climate Change Response Strategy (2015)	Develop national capacity to design carbon projects for accessing carbon financing
National Climate Policy (2017)	Outlines a country's strategies, goals, and actions to address climate change and its impacts. It typically includes measures to mitigate greenhouse gas emissions, adapt to climate change effects, and enhance resilience. National climate policies often involve a combination of regulatory measures, incentives, investments, and international cooperation to achieve emission reduction targets and promote sustainable development.

Instrument (Policy/Legislation)	Scope
Carbon credits trading (general) Regulations SI 150 of 2023 and SI 152 of 2023	The Statutory Instrument 150 of 2023, also known as the Carbon Credits Trading (General) Regulations, was gazetted in Zimbabwe to provide control and management over all carbon credit trading projects within the country1. This regulation affects the Forest Reference Emission Level (FREL) by establishing a framework for monitoring, reporting, and verification, which is essential for ensuring the integrity of carbon credits related to forestry projects.
Nationally Determined Contribution	In Zimbabwe, NDCs are its commitments under the Paris Agreement to cut emissions and adapt to climate change. They outline strategies for reducing greenhouse gases and building resilience, considering national circumstances. These plans are submitted to the UNFCCC to contribute to global climate action
Low Emission Development Strategy	A roadmap or set of initiatives aimed at reducing greenhouse gas emissions and promoting sustainable development. It likely includes policies and actions to improve energy efficiency, expand renewable energy sources, enhance agricultural practices, and conserve natural resources such as forests

Table 1.2. Main measures contributing to reduction of deforestation and degradation

Description of mitigation action	**Status**	**Projected non-GHG effects**	**Comments**
Conservation Agriculture	Under implementation	Improved food security and improves soil fertility	Supported by government through climate smart agriculture practices, including conservation tillage (*Pfumvudza/intwasa*).
Fruit Tree Planting (Horticulture scheme)	Under implementation	Improved food security and reduced soil losses	Supported by government
Reduction of area burnt	Under implementation	Reduced air pollution and soil nutrients loss	Initiatives by EMA and Forestry Commission
Reforestation/Afforestation (Tobacco Wood Energy Project)	Under implementation	Reduce deforestation in tobacco growing areas	Supported by government
Bio-energy Initiatives	Planned	Improved energy availability and broaden income sources	Supported by the government
Global Environmental Facility project	Under Implementation	Implementation of sustainable forest management practices in Save and Runde Catchment	GEF 7 targets to restore about 130, 000 Hectares

Description of mitigation action	Status	Projected non-GHG effects	Comments
Voluntary Carbon Projects	Planned and under implementation	Broaden income sources	One REDD+ project under implementation and several planned projects at feasibility stage

1.3.FREL Development in Zimbabwe

In response to the challenges described above, the FAO Country office launched a project titled "*Strengthening Capacities of National Institutions for Sustainable Forest Management and Climate Change in Zimbabwe*," which is funded by FAO. One of the outcomes of this project was specified as Zimbabwe's first-ever FREL report. FAO forest resources assessment (FRA) experts from the Rome office worked with a national consultant (MRV expert) to build the capacity of the country's mapping and inventory experts to collect and process data that culminated in this FREL document subsequently reviewed and adopted by the country's National Designated Authority and submitted to UNFCCC. This FREL is submitted as the first iteration of several planned updates that will follow a stepwise approach informed by improvements in data availability and quality, country needs, and technological advancements. Zimbabwe's first-ever FREL ensures consistency with all prior, current, and future GHG inventory reporting procedures and is guided by IPCC's reporting principles of Transparency, Accuracy, Consistency, and Comparability.

1.4.Objective

The main purpose of developing this FREL was to provide an objective benchmark that enhances Zimbabwe's capacity to assess the performance of REDD+ activities within the country. The FREL is not intended to prejudge Zimbabwe's Nationally Determined Contribution or any other mitigation actions. This FREL submission is the first stage of a stepwise approach, that will be followed by future iterations informed by country needs and improvements in data availability and technologies.

1.5. Consistency with GHG Inventory Reporting

The Ministry of Environment, Climate, and Wildlife is responsible for the overall regulation and reporting of the GHG inventory for Zimbabwe to the UNFCCC. The climate change management department, under this ministry is the national designated authority (NDA), mandated with promoting best practices in climate change adaptation and mitigation and coordinates with several departments and parastatals such as Forestry Commission, Environmental Management Agency, Zimbabwe Parks and Wildlife Authority, and other cross-ministry departments such as lands, agriculture, water, rural development, and health to provide the information required to compile and subsequently submit the reports for the country.

Zimbabwe's latest GHG inventory reports such as the Fourth National Communication (FNC) and the revised Nationally Determined Contributions (NDC), 2021 used default emission factors derived from the IPCC 2006 Good Practice Guidance (GPG) and emission factors database in calculating emissions. This FREL is a step-up improvement of the reporting process as it uses a hybrid of national forest inventory data collection between 2016 and 2023 for the forested areas and IPCC default values for other land covers where national inventory is not yet achieved. Therefore, the data used in this FREL development will benefit future national communications and the respective biennial updates.

2. Scale

Zimbabwe has decided to use the national scale for her first FREL so as to provide broad sectoral technical guidance to support REDD+ projects in the absence of a Jurisdictional REDD+ program. The decision is also greatly informed by the current national forest inventory program that uses a national grid. Depending on the yet-to-be-developed Jurisdictional nested REDD+

program, future FRELs may be developed at a different subnational scale such as the provincial scale but the FREL itself remains national.

The FREL excluded commercial plantation forests. The total present-day non-plantation forest area is ~13.6m Ha comprising reserved areas (gazetted forest reserves, national parks, safari areas), and private and communal forests. This constitutes ~35 % of the country's total land area. Reserved areas alone contribute ~25 % of the forested land, while their total extent (including non-forest) covers ~ 14 % of the total country's land area. The forest land comprises mostly dense and open woodlands. The woodlands, whether dense or open can be generally broken down into five subcategories: mopane woodlands (dominated by *Colophospermum mopane*), miombo woodlands (dominated by *Julbernadia globiflora, brachystegia boehmii,* and *Brachystegia spiciformis*), teak woodlands (dominated by *Baikiaea plurijuga*), and acacia woodlands (dominated by a mix of species in the *Vachellia*, *Terminalia*, and *Combretum* genera).

However, a few patches of natural moist montane forests are also present, especially in the Eastern highlands of the country. Figure 2.2 below shows the country's forest cover probability as of 2022 (i.e., at the end of the historic reference period and beginning of the projection period), derived from the analysis of ALOS-PALSAR radar data as explained in section 4.3.

Montane forest Miombo forest

Figure 2.1. Examples of forest types in Zimbabwe.

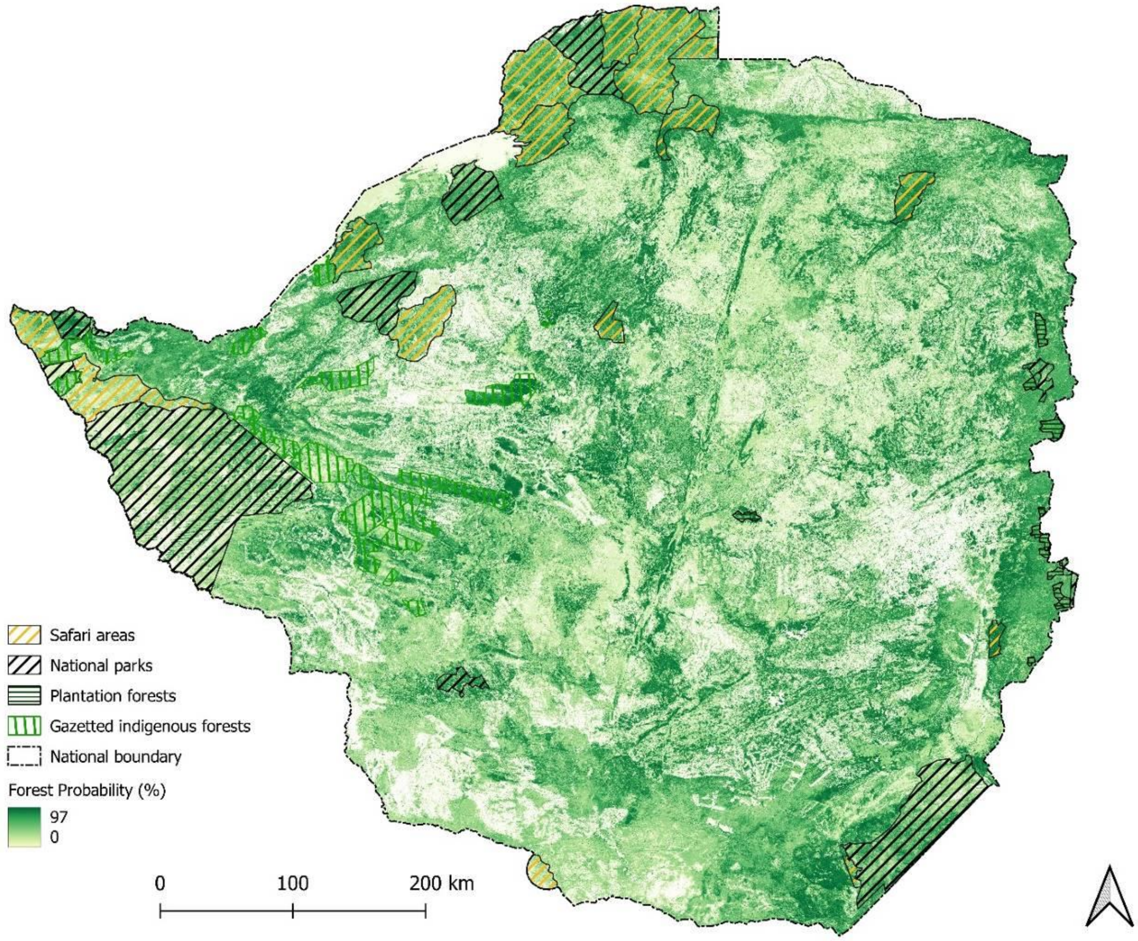

Figure 2.2. Zimbabwe forest cover probability benchmark map, 2022

3. Scope

3.1. REDD+ Activities

Zimbabwe's first FREL considers CO_2 emissions from deforestation only. The post-conversion land use/landcover (LULC) classes considered during the Activity Data analyses, following IPCC classification guidelines, are cropland, grassland, wetland, settlement, and other. Deforestation is defined as the conversion of natural forest land to non-forest land. This excludes planned felling of plantation forests, which are under a rotational harvesting and replanting scheme. Forest degradation is not reported in this FREL although Zimbabwe has already begun the process of analyzing the data for this activity. The progress regarding forest degradation thus far is presented in Appendix 9.1. Therefore, the 5 main direct deforestation activities analyzed during activity data assessments and reported in this FREL are:

1. Forest to Cropland
2. Forest to Grassland
3. Forest to Settlement
4. Forest to Wetland
5. Forest to other

Forest cover was not stratified into intact and degraded, due to data limitations. If degraded forest comprised the majority of the initial forest cover, then emission factors for conversion to other land uses are logically lower compared to those of conversion from intact forests. Thus, Zimbabwe decided to use an average forest class carbon density to ensure that the emissions are not underreported. Therefore, deforestation for this FREL captures conversion from both forest classes (intact and degraded) as an average.

Zimbabwe acknowledges that forest cover dynamics within the country also involve removals in the form of enhancements, sustainable forest management activities, and forest conservation. However, at the moment, the country lacks the capacity to accurately report for this in a FREL, thus it is considered as a subject for future improvements.

3.2.Pools

The carbon pools reported in the current FREL submission are aboveground biomass (AGB) and belowground biomass (BGB) only. This is due to their significant contribution and availability of data and accuracy of estimation methods for these two pools and the lack of such for other pools like deadwood, litter, and soil organic carbon. Literature-based default values for these excluded pools could also not be used due to the high uncertainty associated with the data. However, as measurement resources and capacity continue to grow, Zimbabwe will consider including more pools in subsequent FREL submissions.

3.3.Gasses

The current FREL covers Carbon dioxide (CO_2) only as it is the main gas of concern and the one for which reliable spatial data is available. Nevertheless, anthropogenic sources such as wildfires, landfills, and agricultural activities result in the release of these other non-CO_2 gases such as Methane (CH_4) and Nitrous Oxide (N_2O), thus they may be considered in future FREL submissions. However, most of the dominant miombo woodlands in the forest cover category are known to be fire-adapted, thus further research will have to be conducted regarding the significance of the contribution of these other gases before they are actually reported in any FREL.

4. Procedure and Information Used (Building Blocks)

4.1. Definitions

For consistency purposes, the same FAO forest definition used in the Forest Resources Assessment (FRA) reports is adopted for this FREL. Forest is defined as a minimum of 0.5 Ha with 10% canopy cover from trees that are or capable of exceeding 5m in height. This definition is used in the national forest inventory program when assessing aboveground biomass in the forest land cover category. Exotic plantation forests, although meeting this definition, were excluded from the calculations of deforestation. Only natural forests are, therefore, included in the forest definition for the purposes of this FREL. The locations of these exotic plantation forests are known. They are mostly found in the Eastern Highlands and comprise mainly conifers (mostly pine) and eucalyptus species.

4.2.Historic Reference Period and Data

Zimbabwe decided to submit the Forest Reference Emission Level at a national scale using a 6-year reference period of 2016-2021 (inclusive). The selection of the reference period was mainly based on data availability, quality and requirements of carbon standards with methodologies that support Jurisdictional REDD+ programmes. Moderate-resolution optical and radar data from the EU's Copernicus program started to be available in 2015. (Sentinel-1 & 2) The first high-resolution planet mosaics, provided under the NICFI program, became available at the end of 2015 while ALOS-2 PALSAR-2 ScanSAR radar imagery is available from 2014. The availability of these different data sources improves the capability of stratifying the country into meaningful zones of forest, non-forest and forest change, thus efficiently informing the sample design within the sample-based area estimation approach used for the area estimation procedure explained hereafter.

4.3. Activity Data

4.3.1. Introduction/Background

According to the IPCC guidelines, estimates for area change need to be unbiased and uncertainties should be quantified and reduced as much as practicable. While maps offer a comprehensive visualization of spatial data, facilitating the analysis of patterns and trends, they are prone to errors and thus provide biased estimates if areas are directly calculated from the underlying pixels (Olofsson *et al*. 2014, 2020). In addition, it is difficult to derive the uncertainties surrounding the estimates using a map pixel count. Sample-based area estimation (SBAE) is a recommended practice, as this method provides unbiased results and confidence intervals can be deducted to provide an estimate of the precision of the reported values (GFOI MGD)[3].

However, ensuring that change events are adequately captured by the sampling design in an SBAE remains a challenge, as they are rare events, meaning that they cover only a small portion of the total land area in a country. It is, therefore, crucial to adopt an approach that captures these events reliably. In recent years, stratified area estimates have gained popularity for meeting carbon standards requirements, as stratification of the samples provides a more efficient way of capturing rare events with lower levels of uncertainty as compared to simple random or systematic sampling designs(Olofsson et al., 2014; 2020, Jonckheere et al., 2024).The layer for the stratification is still derived from a categorical classification of underlying satellite data as

[3] https://www.fao.org/gfoi/overview/en/

within the map pixel count approach, but the final estimates are derived from the samples, only taking the map classes as strata into account throughout the estimation process. Therefore, the final estimates are sometimes also referred to bias-adjusted map estimates.

One of the well-known challenges with this approach is the influence of missed change in the stable stratum (i.e. omission error) that negatively affects the precision (Olofsson *et.al*., 2020). In order to counteract this problem, the underlying method for stratification used in this FREL submission uses a continuous layer of change probability for the derivation of map strata, allowing for an optimal sample allocation (Cochran 1977). This type of stratification has been applied to estimate forest change in a robust and unbiased manner, providing high levels of precision (Broich et al., 2009, Pickering et al., 2019)

As such, the estimates presented within this document are based on the well-established and recognized technique of sample-based area estimation using stratification, which is in accordance with the guidance principles of unbiased estimates of forest and forest change (IPCC, GFOI). The sole difference is introduced in the stratification of the sampling design, where a statistically optimized approach is taken to ensure an efficient sample allocation. It is important to note that this difference does not affect the estimate, as it can still be considered unbiased, but rather tries to increase the precision around that estimate, ultimately leading to a more reliable result. Zimbabwe recognizes that this approach is relatively new and has not been used so far by any party in the UNFCCC submission process of a FREL. Moreover, as the stratification is at the heart of the sampling design, the subsequent remarks will mainly focus on how the stratification layer and the underlying change probability is derived.

The use of a proxy map of forest change probability is deducted from the difference of two layers (beginning and end of reference period) of forest probability, that both, in turn, are derived from a forest/non-forest (FNF) classification exercise. As the classification process can be regarded as independent from the input satellite data, this approach is considered robust in time, as new sensors can be integrated to create those base layers. The FNF maps can be further enhanced in a later step and may also serve other purposes important to natural resource management as well as national and international reporting.

The activity data assessment was aligned with parallel activities under the Forest Resource Assessment - Remote Sensing Survey (FRA-RSS), meaning that selected samples overlap with the country's existing hexagonal equal area grid from this project to ensure consistency between both workstreams.

Alignment with FRA - RSS

Zimbabwe is actively participating in the Forest Resource Assessment (FRA) program reporting conducted by FAO. Notably, the country served as a pilot during the initial FRA Remote Sensing Survey (FRA-RSS). As part of this initiative, the FRA team created a systematic, equal-area hexagonal grid consisting of 987,556 points over Zimbabwe using the DGGRID library (Sahr, 2019), where each sample represents 40 hectares. Zimbabwe decided to use this same grid for the Forest Reference Emission Level (FREL) assessment to facilitate streamlined and cohesive data collection and management. This means that the locations of the final samples selected for activity data assessment are a subsample of the FRA grid.

Training Data Collection

A time-series and subsequent change analysis was performed over a reduced set of samples from the FRA grid (246,889 samples). Information from various time-series algorithms for change detection (BFast, CCDC, CuSum, EWMA), together with aggregated statistics of the time-series itself, as well as auxiliary information from global products were used in an unsupervised K-Means clustering. Each cluster was then further subsampled to derive a total of 1,000 training data points that included a wide variability of the different landscapes as well as locations of change. The visual interpretation of training data was executed using the Collect Earth tool from the Open Foris family, developed by FAO. Information was collected on Land Use Land Cover (LULC) changes using IPCC classes descriptions.

It is worth mentioning that this selection process was targeted at a slightly different way of stratifying, in which time-series is solely extracted for the sample point locations from the FRA grid to obtain a change probability value. As the resulting stratification out of this process did not show any significant sensitivity to change, a simplified and more adequate stratification approach for the prevailing dry forest landscape was adopted that is described hereafter. As the relevant information of forest/non-forest is captured within the selection described here, the collected data could be equally used for the generation of forest probability maps as used in the adopted wall-to-wall approach.

The use of forest probability difference maps for stratification and sample allocation

An auxiliary continuous variable related to change can inform a stratification in an efficient manner to reduce uncertainties in the estimation process of forest and forest change area and still guarantee an unbiased estimate (Broich *et al*., 2008, Pickering *et al*., 2019). There are different ways to create such a layer from remote sensing-based products. The method utilized in this FREL submission makes use of the underlying probabilities derived through the supervised classification process of forest/non-forest using a multi-sensor image stacks. Supervised classification is a well-established technique in remote sensing that turns the satellite's reflectance data into thematic information. The usual output of such a process is a categorical value for each pixel, e.g. forest or non-forest. A more nuanced output can be obtained, too, that holds the information of how certain the classifier is that a pixel belongs to one or the other class, which is referred here as (forest) probability output.

In a first step towards the generation of the stratification, the probability output for the forest class in a simple forest/non-forest classification is retrieved using the Random Forests algorithm (Breiman, 2001). The values range from 0 to 100 as depicted in Figure 4.1 (A) and (B). This classification is repeated for both the start (2016) and one year after the end of the envisaged reference period (2022). The classification is done using FAO's SEPAL platform where stable forest and non-forest samples from the above-described training data collection process were used as training data. The decision to use a buffer year at the end of the reference period is to avoid missing the change that predominantly takes place at the end of each year and thus might be missed in the FNF classification, and subsequently in the stratification.

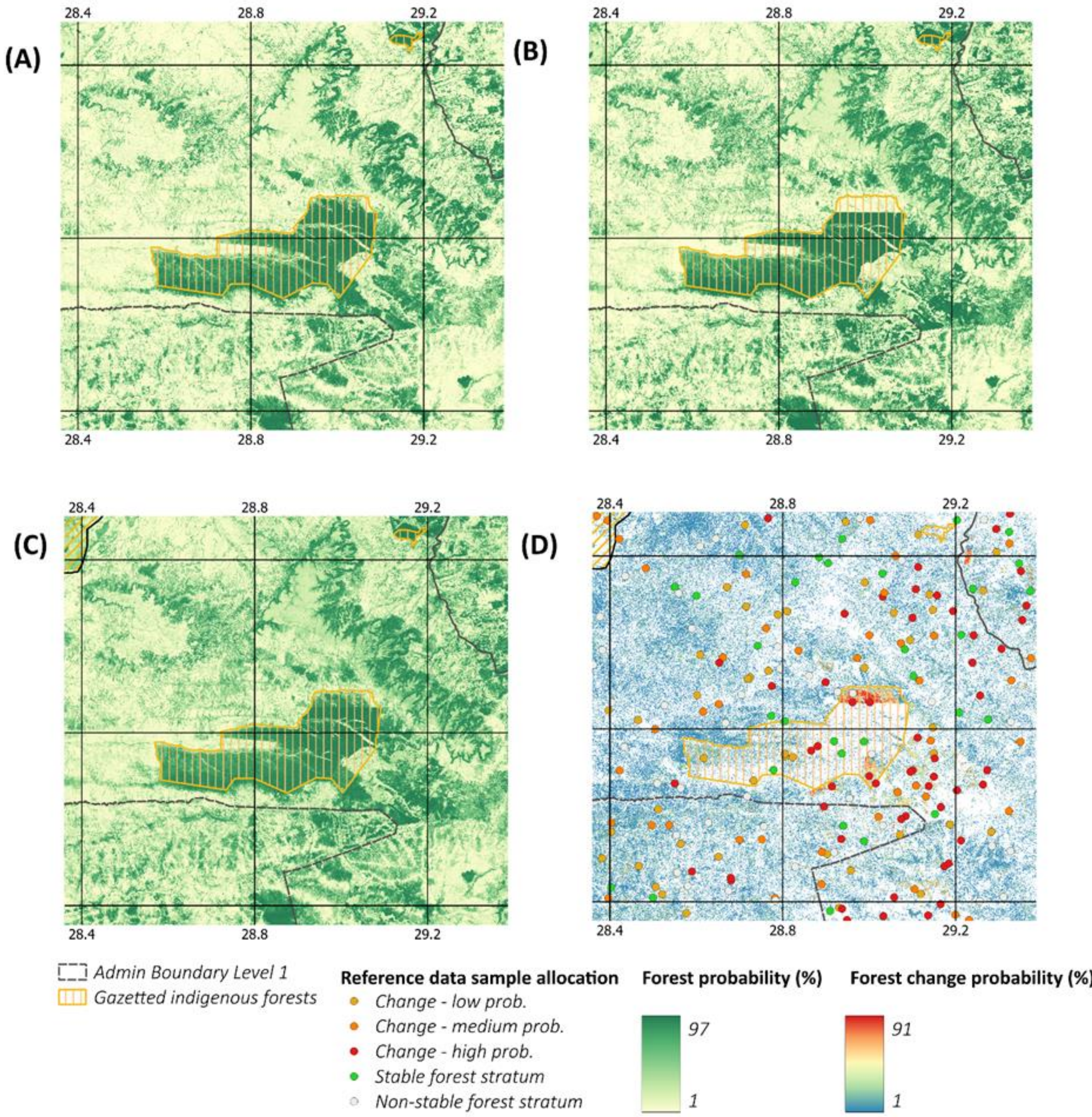

Figure 4.1. An illustration of the novel stratification approach used in the FREL development process.

A) is Forest non-Forest (FNF) probability map of 2016, B) FNF probability Map 2022, C) Maximum Forest probability (2016,2022) D) Forest change probability clamped to 1 – 100 for the reference period. Allocation of reference sample points at the zoomed area are also shown, divided into five categories.

In a second step, the difference of both probability layers is calculated, and values are clamped between 0 and 100 as the interest is only in forest disturbance probability, reflected by a drop in forest probability (Figure 4.1 (D)). As a result, the derived probability difference layer represents a proxy for forest change, as the assumption is that a true change of tree cover on the ground will ultimately lead to a difference in forest probability between the two FNF classifications. Furthermore, it is assumed that those changes are sometimes subtle, so they do not always show in the categorical FNF maps. By using the continuous probability output of the forest classification instead, we also retain small differences between the 2 classifications, capable of detecting partial loss in tree cover. The workflow for the derivation of the change probability layer is depicted in Figure 4.2.

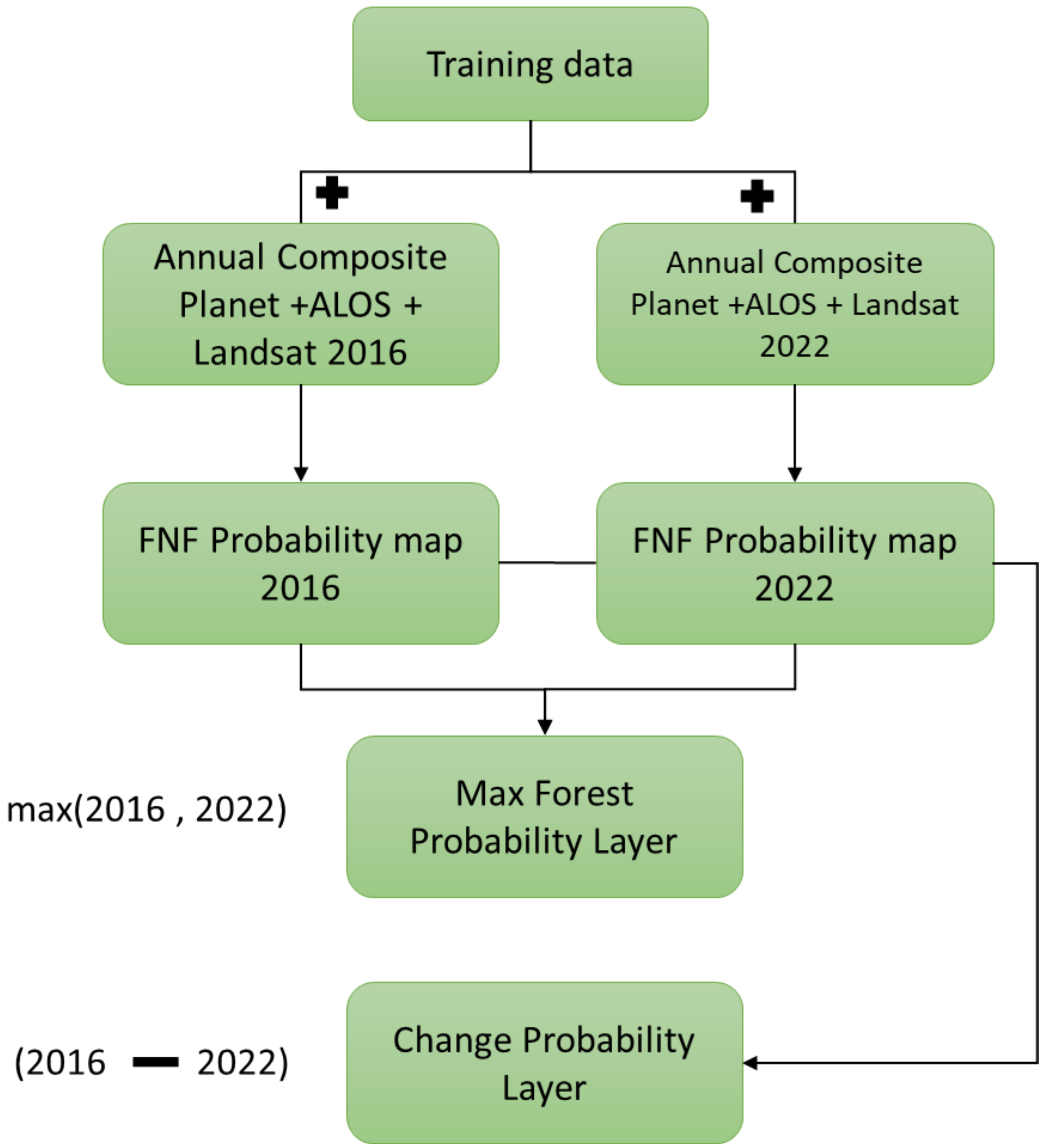

Figure 4.2. The workflow for creating forest non-forest (FNF) probability maps for 2016 and 2022 using multi sensor data.

Maps were generated using SEPAL[4] cloud platform developed by FAO. These annual maps served as the basis for extracting two layers: Maximum Forest probability and Change probability. The continuous layer of change probability provides two additional statistical advantages. Firstly, strata boundaries can be determined from the distribution of the change probability using the K-Means algorithm. Originally designed for clustering, this algorithm is also efficient in optimizing the identification of ideal boundaries for stratifying skewed populations (Kozak, 2011). Secondly, the change probability serves as input in the subsequent sample allocation by employing the optimal sample allocation method proposed by Neyman (Cochran, 1977). Assuming that the proxy of change probability is correlated with the actual occurrence of change on the ground, the use of Neyman allocation ensures that the sampling procedure is conducted in the most efficient manner, resulting in the lowest possible uncertainty derived from the number of samples collected.

The sampling allocation was further optimized by only considering the parts of the land likely to contain all forests and forest changes. The potential forest mask was constructed using the highest value of forest probability at either time 1 or time 2 (Figure 4.1.(C)). A threshold of 15% forest probability for each layer was considered sufficient to ensure the full inclusion of all forests, acknowledging that the FNF map itself is not a perfect representation of the actual forest on the ground, and even lower forest probability values may overlap with actual forest. In other words, the low threshold shall ensure that no forest is missed under this mask.

Similarly, a 15% threshold was applied to the probability difference layer to ensure that all change events were covered. The K-Means stratification and the subsequent Neyman sample allocation was applied to the reduced area using both masks with three change strata (Figure 4.1 (D)). To report not only on forest change but also on the total area of stable forest and non-forest , two additional strata were introduced outside this mask, and convenience sample allocation was used. This ensures that changes falling outside the mask are eventually captured and considered in the area estimation process. As the sample selection should be restricted to the locations of the

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[4] https://sepal.io/

dense FRA grid, the locations of the FRA grid were sampled from the wall-to-wall change probability and maximum forest probability layers. Subsequently, the points were stratified as explained above into stable non-forest, stable forest, and the three change strata. The selection process is depicted in Figure 4.3, including the final number of samples allocated to each stratum. The satellite imagery used as input data for the classification is shown in Table 4.1 and more detailed information is outlined in Box 1.

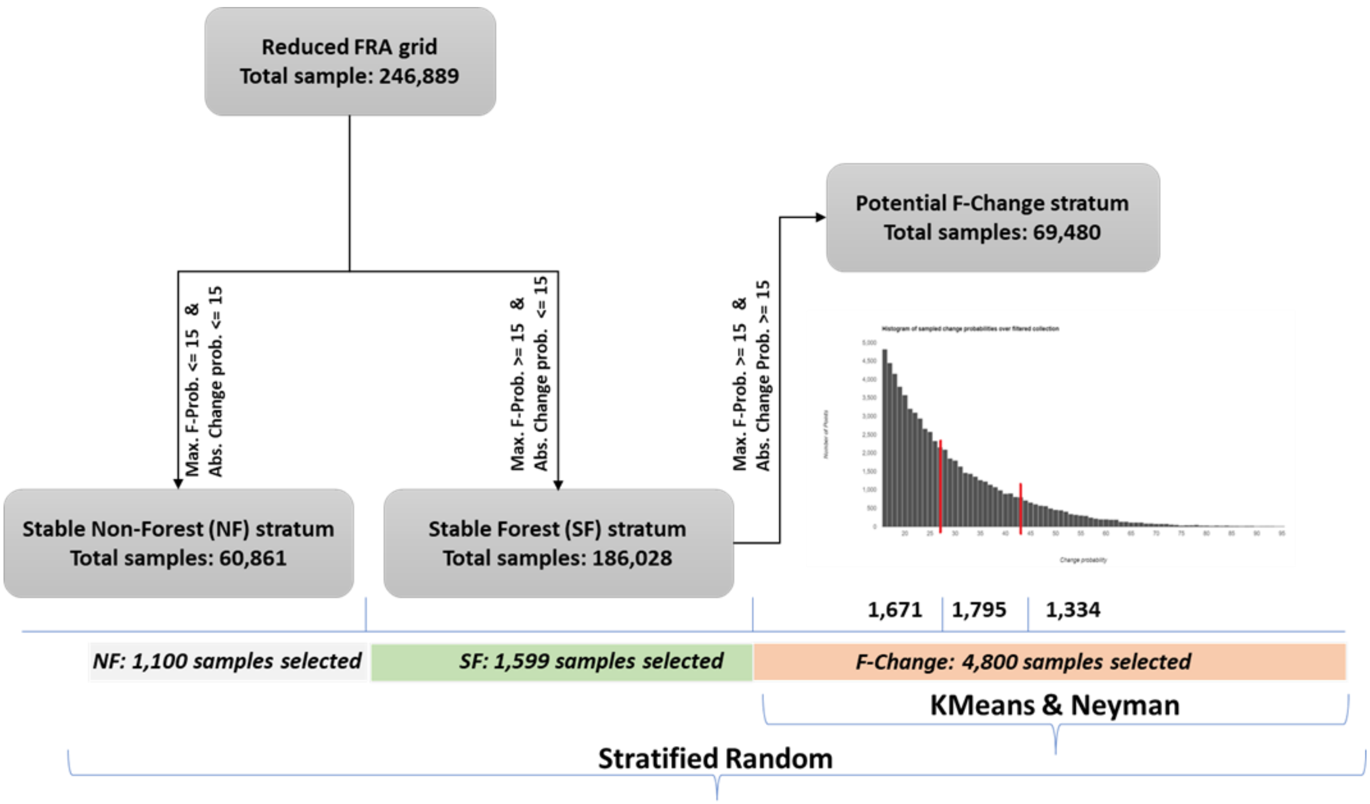

Figure 4.3. Stratification of activity data sample points.

A reduced FRA grid was superimposed over the maximum and change probability layers, using the threshold of 15 % to create the stable forest and non-forest strata. The same layers were then used to select the potential change stratum i.e., where maximum and change probability was >= 15 %. This resulted in the potential forest change stratum and the K-Means algorithm was eventually used to define strata boundaries. Neyman allocation was then applied to allocate samples.

Table 4.1: Satellite imagery and bands used for classification.

Satellite	Bands Used	Index
Landsat	Red, NIR, SWIR1, SWIR 2	Normalized difference of all available band combinations
Planet (NICFI)	Blue, Green, Red, NIR	NDVI
ALOS-PALSAR	HH median HV median	Simple ratio of HH and HV median

This novel approach has notable advantages over other types of stratification of change. Firstly, training data on change, which is usually hard to get, is not necessary, as only the knowledge about stable forest in the time of interest is necessary to construct the change probability layer used for the stratification. As the occurrence of forest is abundant, the minimum number of samples for subsequent classification does not pose a problem. Another advantage is that the two classifications can come from any combination of sensors. This makes the approach future-proof, meaning that new data sources can be easily integrated into the classification procedure without changing the overall methodology. From the experience of developing this FREL, it was evident that annual composites of forest probability are better suited to detect changes in the dry forest environment than time-series algorithms that are sensitive to seasonality, which ultimately improves stratification and, therefore, precision around the statistical estimates of forest and forest change.

Moreover, the continuous proxy variable created for the subsequent stratification allows for an optimal sample allocation based on Neyman, which optimizes the cost-benefit for visual interpretation. Further advantages are that by subtracting the forest probabilities of time 1 and time 2, both gain and losses can be considered, and the increased sensitivity from the more nuanced information allows for detection of degradation too. Finally, the creation of the underlying FNF classification is streamlined through FAO's SEPAL platform and can be achieved within a few days. The generated analysis-ready input data from various satellites can be directly used in additional mapping exercises, such as LULC mapping, or the derivation of bio-physical properties such as tree height or biomass. Those products are of great value for natural resource management and monitoring, as well as various reporting obligations of the country.

Box 1: Satellite Imagery selection and processing

After the visual inspection of the various available data sources, a set of three different layers for both 2016 and 2022 were selected. The **Landsat** data utilized in this process was sourced from the Global Forest Change dataset, accessible via Google Earth Engine. For classification purposes, the Red and Infrared bands were extracted from this pre-processed and analysis-ready annual reflectance data for both years (2016 and 2022).

The **Planet NICFI Annual composite** was processed using FAO's System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL) platform, creating an average image for all data available throughout the year of interest, applying additional cloud masking and advanced pixel selection**.**

ALOS-2 PALSAR-2 analysis-ready data is available through Google Earth Engine. To take advantage of its capability to sense the Earth independent of clouds, all of the individual scenes were used to create yearly aggregates of the data, calculating the minimum, maximum, median, and standard deviation over each pixel. This process is also known as a timescan. The radar time scan data is a valuable source that indirectly captures greening and leaf-off seasons independent of their occurrence timeline due to the simple usage of minimum and maximum values. These characteristics make them more robust to the intra-annual variation and ease the process of separating forest and non-forest areas. As part of the feature engineering process throughout the classification, further indices and ratios between various bands were added to improve the separability between forest and non-

4.3.2. Activity Data Collection

Sample point interpretation was done for the years 2016-2022 (both inclusive), utilizing the Collect Earth tool, complemented by high-resolution satellite images from multiple sources such as Google Earth Pro, Bing maps etc. The Google Earth satellite imageries are detailed and presented at less than one-meter spatial resolution but do not provide a continuous coverage. The scarcity of detailed temporal information over sample plots hampers the ability to make informed decisions. Recognizing this impediment, Zimbabwe opted to leverage Norway´s International Climate and Forest Initiative (NICFI) freely available, monthly Planet data as a supplement throughout the interpretation process. This strategic decision facilitates a more streamlined data collection process, enabling the utilization of more recent, temporally dense, and thus more reliable information for the determination of forest and forest change, which ultimately improved the estimation process of the FREL.

The exercise also incorporated Landsat 8 and Sentinel-2 annual composites where needed for comprehensive data acquisition. The data collection approach is shown in Figure 4.4. Data was collected in a backward style, where first information about Land Use Land Cover (LULC) in 2022 was collected. Then in case of change, further information about the year of change, driver of change and LULC class for the respective year was collected. Using this survey, interpreters were able to collect up to four maximum changes. No multiple changes were observed between 2016 and 2022.

Though the data collection period was 2016 -2022, inclusive, the current FREL calculations are only up to 2021. This is due to the limitation of using annual composites, where changes that occur towards the end of the last year in the time series are likely going to be missed since the image composites do not always coincide with the last day of the year, but rather represent a selection of best pixels that might occur at any time of the year. The consequence for the subsequent sampling is that omissions of change would either remain undetected and thus introduce a negative bias or fall into the stable strata and reduce the certainty of the estimate.

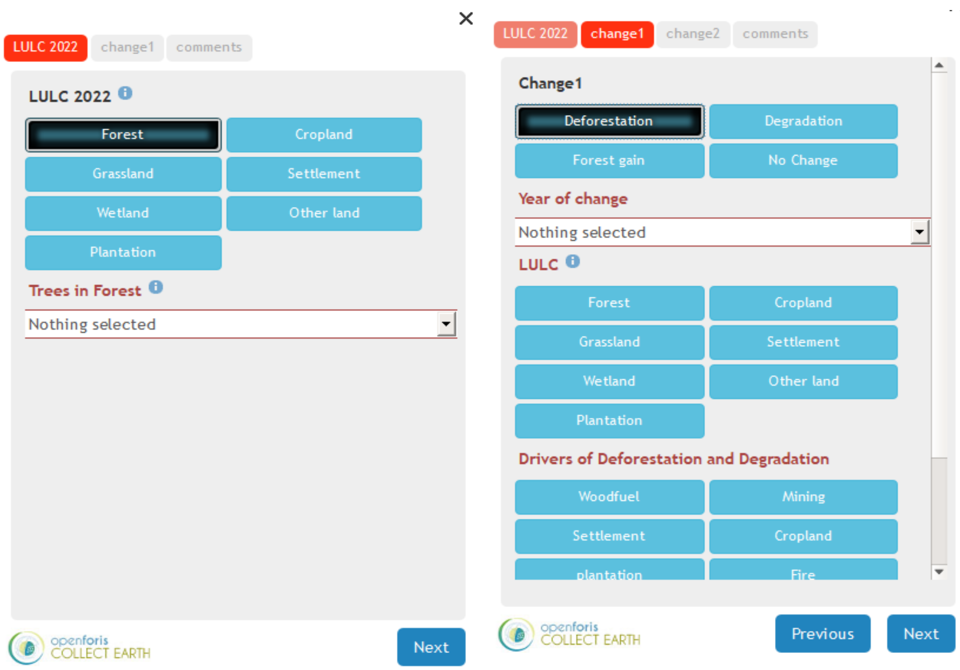

Figure 4.4. Survey card design used for data collection.

4.3.3. Results

Table 4.2. Historic reference period forest change estimates.2 shows the forest change area estimates for the historic reference period of 2016-2021 (inclusive). As of now, Zimbabwe lacks nationally established definitions for deforestation and forest degradation. Therefore, a response design was formulated, leveraging the IPCC classes. The country has opted to align with the FAO forest definition to maintain consistency with other concurrent projects. For a comprehensive understanding of the land cover classes, detailed definitions are provided in Appendix 9.4.

Table 4.2. Historic reference period forest change estimates.

Change Type	**Change Area (Ha)**	**U (%)**	**95 % CI (Ha)**
Deforestation	236,695.3	22.6	53,373.8
Degradation	83,006.8	50.9	42,291.5

The drivers of deforestation and forest degradation identified during the Activity Data analyses are shown in Figure 4.5. Historic reference period drivers of deforestation and forest degradation.5. These drivers were further grouped into 3 main activity classes according to the IPCC classification system: Cropland, Settlement, and Others.

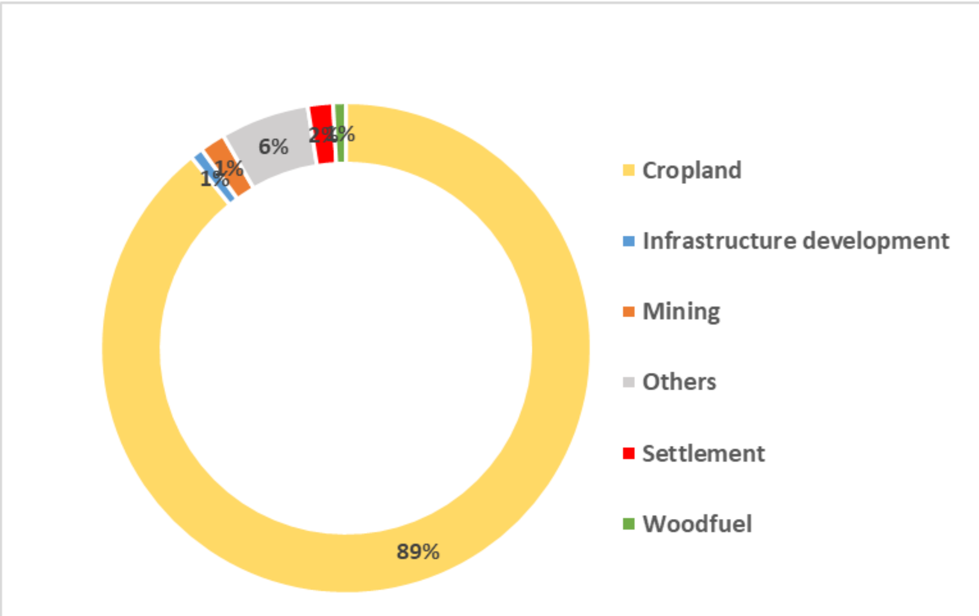

Figure 4.5. Historic reference period drivers of deforestation and forest degradation.

4.3.4. Area Estimates for REDD+ Activities and Associated Uncertainty

The results of the sample point interpretation were used to derive the area estimates and associated uncertainties for stable forest, stable non-forest and the change classes following the standard estimation process for a stratified random sampling design (Cochran 1977, Lohr, 2019). The estimator of the total population *mean* for stratified random sampling is calculated as follows:

$$\bar{y}_{str} = \sum_{h=1}^{H} W_h \bar{y}_h. \quad [4.1]$$

In the case of area calculation this population *mean* $\bar{y}_{str}$ represents the fraction of land occupied by a specific category. The overall population *mean* $\bar{y}_{str}$ is a weighted average of the sample means $\bar{y}_h$ within each stratum *h*, where $W_h = {}^{N_h}/_{N}$ or equivalently, $W_h = {}^{A_h}/_{A}$ reflects the stratum weights in the total population.

The estimation of the sample mean $\bar{y}_h$ for each stratum h, is calculated as follows:

$$\bar{y}_h = \frac{1}{n_h} \sum_{i=1}^{n_h} y_{hi} \tag{4.2}$$

where n_h represents the total number of reference samples within stratum *h*. y_{hi} represents the observation of category *i* within stratum *h*, where the observation *y* is 1 for a sample that falls under the category, and 0 if it represents another category.

The final area estimate for each category is derived by calculating the population *total* $\hat{t}_{str}$, which is estimated by summing the product of the sample mean $\bar{y}_h$ with the product of the number of samples within the total population N_h (i.e. the underlying FRA grid) and the expansion factor ε (160 ha) for each stratum *h* as follows:

$$\hat{t}_{str} = \sum_{h=1}^{H} \bar{y}_h \, N_h \, \varepsilon \tag{4.3}$$

The estimator of the variance of the population *mean* (proportion samples) for stratified random sampling is measured using ((Lohr, 2019) Eq. 3.5):

$$\widehat{Var}(\bar{y}_{str}) = \frac{1}{N^2} \sum_{h=1}^{H} \left(1 - \frac{n_h}{N_h}\right) {N_h}^2 \frac{s_h^2}{n_h} \tag{4.4}$$

where the term $\left(1 - \frac{n_h}{N_h}\right)$ is a correction term for the finite population within a stratum and ${s_h}^2$ is the estimated within-stratum population variance, calculated as follows:

$$s_h{}^2 = \sum_{i=1}^{n_h} \frac{(y_{hi} - \bar{y}_h)^2}{n_h - 1} \qquad [4.5]$$

The estimator of the variance of the population *total* $\widehat{Var}(\bar{y}_{str})$ for stratified random sampling is calculated using ((Lohr, 2019), Eq. 3.4) as follows:

$$\widehat{Var}(\hat{t}_{str}) = \sum_{h=1}^{H} \left(1 - \frac{n_h}{N_h}\right) N_h{}^2 \frac{s_h^2}{n_h} \qquad [4.6]$$

where, h represents the stratum number and N_h refers to the size of the total sample population of stratum h.

For the, the standard error for each stratum h is derived as follows:

$$SE_h = \sqrt{\widehat{Var}(\bar{y}_h)}\, N_h\, \varepsilon \qquad [4.7]$$

The final uncertainty estimate uses the 95% confidence interval (i.e. *z-score* = 1.96) and has been calculated as follows:

$$CI = 1.96 \times \sqrt{\sum_{h=1}^{H} (SE_h)^2} \qquad [4.8]$$

The process explained above (equations 4.1 – 4.8) was repeated for each category separately and the results of the area estimates and their associated uncertainties are presented in table 4.3.

Table 4.3. Area estimates of REDD+ activities..

Activity	**Area Estimate (Ha)**	**Uncertainty @ 95 % CI**
Forest to Cropland	211,880.9	24.4 %
Forest to Grassland	0	-
Forest to Settlement	14,117.4	78.6 %
Forest to Wetland	0	-
Forest to Other	10,697.0	68.0 %
Total	**236,695.3**	**22.6 %**

4.4. Emission Factors

Both tier 1 and tier 2 data were used to derive emission factors for the reported REDD+ activities. Carbon density (tCO_2e/Ha) in forested land was estimated from the national forest inventory data (tier 2) collected between 2017 and 2023. Residual carbon densities in the various post-conversion land uses were estimated using the IPCC 2006 Good Practice Guidance default values, refined in 2019[5] (tier 1). Since there is no systematically and consistently collected data on harvested wood products, instantaneous oxidation is assumed. Moreover, most of wood harvesting is in plantation forests, that are managed within a rotational harvesting and replanting scheme.

4.4.1. Carbon densities in the forested land class

The following steps were taken to estimate carbon densities in the forested land class from field sample plots.

1. Calculation of single tree ABG biomass using an allometric equation
2. Calculation of single tree BGB biomass using a root-to-shoot ratio of 0.48 (IPCC default, GPG table 3A.1.8[6])
3. Calculation of total tree biomass (AGB+BGB)
4. Calculation of total plot biomass (Sum of all tree biomasses)
5. Calculation of total plot carbon by using a conversion factor of 0.47 (IPCC default[7])
6. Calculation of plot carbon dioxide equivalent using the ratio of the molecular weight of carbon dioxide to that of carbon (44/12: IPCC default[8])

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[5] https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

[6] https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp3/Anx_3A_1_Data_Tables.pdf

[7] https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

[8] https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf

7. Calculation of carbon density (CO_2e/Ha) based on the ratio of plot size (area) to 1 hectare.

The national forest inventory program is based on the Global Forest Survey (GFS) methodology framework[9]. The framework establishes a multi-stage sampling approach to determine an efficient set of sites for fieldwork. A systematic grid of 5 km2 was laid out, resulting in 6500 potential field inventory plots. Per the framework, all the potential sites must be first surveyed using remote sensing techniques. In the Zimbabwe case, these potential sites were overlaid with the 2017 landcover map (Figure 4.6) to eliminate all non-forest sites. The landcover map was produced through a supervised classification of sentinel-2 multispectral imagery. A Sentinel 2 mosaic dataset for 2017 was classified using machine learning algorithms within Google Earth Engine utilizing training samples physically collected in the field. The resultant map was validated using ground data collected in the same year and the overall accuracy was 92 %, Kappa = 0.82. In 2017, the Forestry Commission's national forest inventory team visited the forested sample sites to perform forest inventory as guided by the GFS framework. An attempt to visit all plots was made but inevitably some plots were discarded due to accessibility challenges. The team assessed each plot on site to evaluate its eligibility for classification as forested land, based on the forest definition presented in section 4.1. Sample sites that were identified to have been falsely classified as forests were also discarded.

[9] https://www.fao.org/3/ae346e/AE346E00.htm#TopOfPage

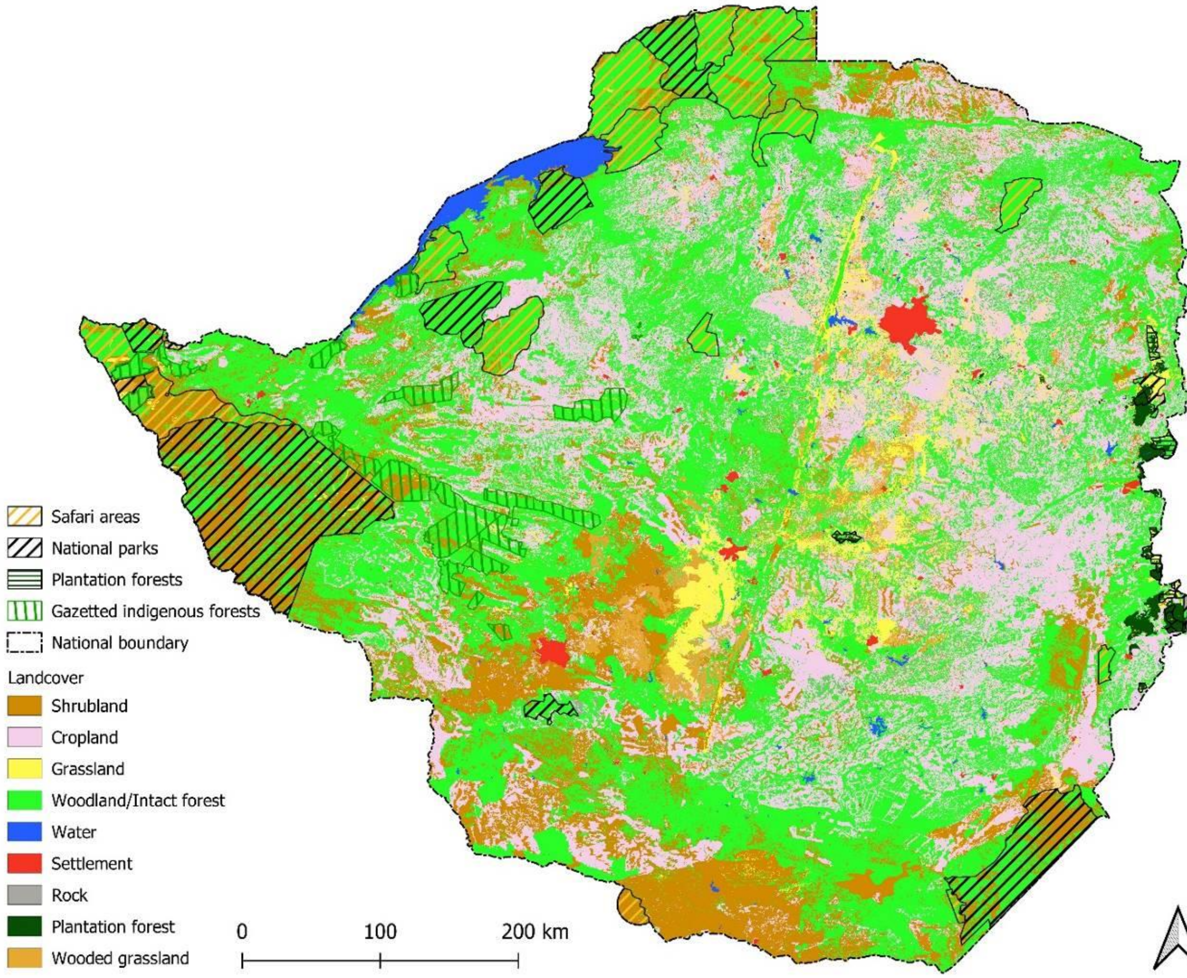

Figure 4.6. Zimbabwe landcover map for 2017.

After the 2017 inventory, a decision was made to further refine the sample plots allocation per the GFS grid and move towards establishing permanent sample plots. Therefore, between 2017 and 2023, several iterations in the refinement of the sample plot allocation resulted in 3 main capacity-building exercises where forest plots were generated and visited for inventory. Further information is presented in table 4.4 below.

Table 4.4. Phases of improvement in the NFI program.

Year	**Exercise**	**Result**
2018	Landcover mapping assessment, validating the 2017 landcover map	Concluded that crucial pockets of forested land, especially Mopane-dominated woodlands were omitted. 9 permanent sample plots were established and measured in 2021, 3 each in the miombo, mopane, and teak woodlands.
2023	Further training of the forest inventory team in the establishment of permanent sample plots	Miombo woodland pockets identified above were randomly assigned 12 sample plots and visited for inventory in 2023.
2023	Further refinement of the 2017 GFS grid based on updated landcover maps	48 additional plots were randomly allocated to both Mopane and Miombo woodlands.

The data that was used for the calculation of forest carbon densities is, therefore, an agglomeration of these 4 forest inventory exercises, with a total of 151 plots (Figure 4.7), that were confirmed as forested land upon field validation. This current sampling effort is low, hence the higher uncertainty in the results presented in section 4.4.2 and has been noted as a priority area of improvement.

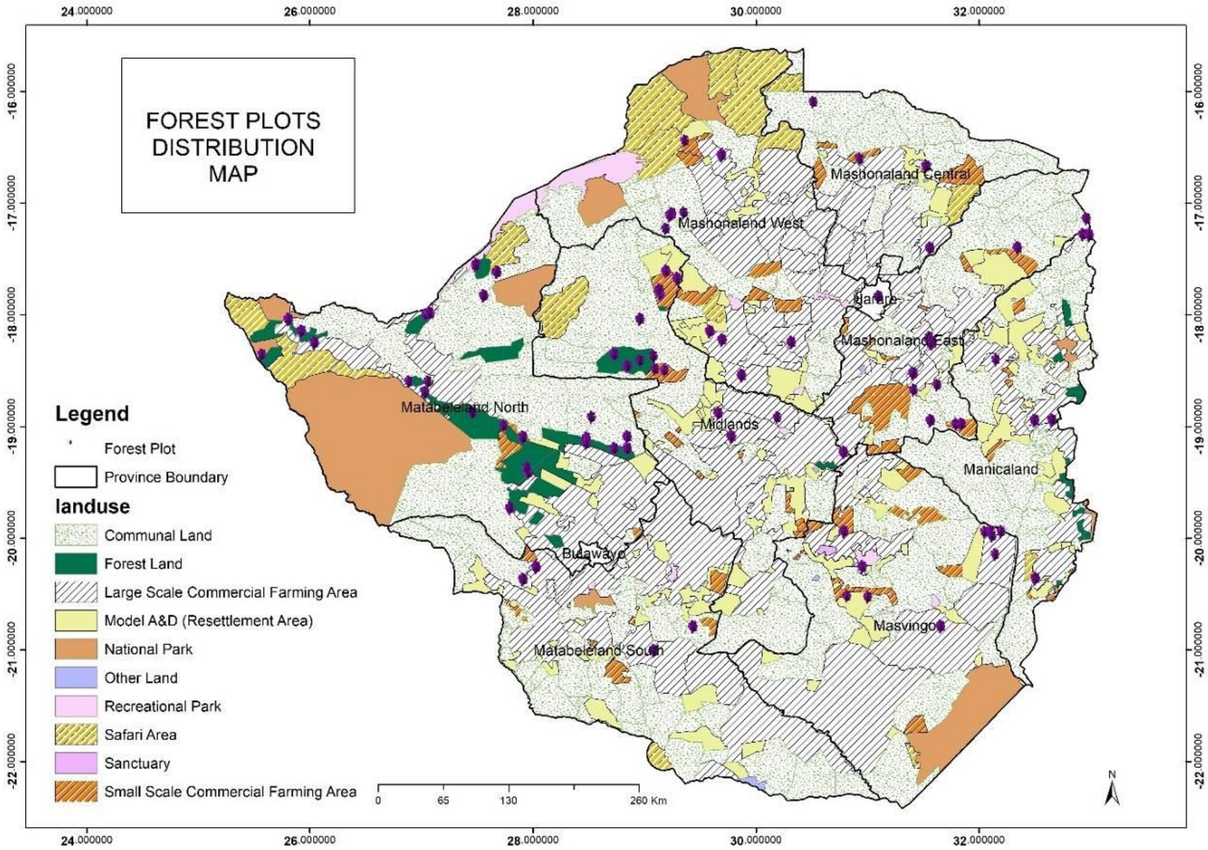

Figure 4.7. Distribution of Forest Inventory Plots.

4.4.2. Allometry

All of the NFI data contained diameter at breast height, while only 2 of these 4 exercises collected tree height in addition. For biomass calculations, it was decided to use DBH-only equations since it is the parameter that was the most accurately and consistently measured. Tree height data is prone to uncertainty since it is indirectly measured. Research has also shown that DBH alone explains more than 90% of the variability in aboveground biomass and that, even when accurately measured, tree height only explains about 2-5% more(Henry et al., 2011).

At the time of submission, the Zimbabwe NFI program does not have a national/standardized allometric equation for ABG calculation. Therefore, literature on allometric equations developed in similar miombo ecoregions was consulted. The following 10 DBH-only generic equations

(Table 4.5. Allometric equations evaluated for aboveground biomass 5) were evaluated on the entire dataset.

Table 4.5. Allometric equations evaluated for aboveground biomass calculations.

Author(s)	**Model**	**Development Site**
Mugasha et al. (2013)	$Y = 0.1027*DBH^{2.4798}$	Tanzania
Chidumayo (2016)	$Y = exp\{-2.059+2.342*ln9DBH)\}$	Zambia
Chidumayo (2013)	$Y = 0.0446*DBH^{2.765}$	Zambia
Guy. (1981); Henry et al. (2011)	$Y = 0.0549*DBH^{2.5101}$	Zimbabwe
GIZ (2012)	$Y = 0.1936*(DBH^{2}*3.1416/4)^{1.1654}$	Southern Africa
Ryan et al. (2011)	$Y = exp\{2.545*ln(DBH)\}-3.018$	Mozambique
Kachamba et al. (2016)	$Y = 0.2169*DBH^{2.3184}$	Malawi
Zahabu et al. (2004)	$Y = 0.0625*DBH^{2.553}$	Tanzania
Brown (1997)	$Y = exp\{-1.996+2.32*ln(DBH)\}$	Tropical dryland forests
Guedes et al. (2018)	$Y = 0.1754*DBH^{2.3238}$	Mozambique

It was found that the Chidumayo (2016), GIZ (2012), Kachamba *et al*. (2016), Brown (1997), and Guedes *et al*. (2018) models had the lowest uncertainties, ranging between 24 and 24.5 % at the 95% confidence interval. Consequently, Zimbabwe decided to use the GIZ (2012) model since it was developed in line with IPCC Compliant MRV Systems objectives. The carbon density for the forest class was determined to be 40.1 tC/Ha = 146.9 tCO2e/Ha. As explained in section 3.1, the forest carbon density value used is an average of intact and degraded forests. When the NFI program is improved to properly stratify forest lands, future FRELs will report separate carbon densities for intact and degraded forests. In the future, Zimbabwe is planning to perform some destructive, but objective sampling in order to derive her own national/standardized generic allometric model(s).

4.4.3. Residual carbon densities in post-conversion land use classes

Table 4.6. Post-conversion Carbon densities tier 1 data.6 below shows the tier 1 carbon densities that were obtained from literature for all non-forest land use classes. These are derived from the IPCC good practice guidance tables from the relevant chapter of each land use category, as specified in the table.

Table 4.6. Post-conversion Carbon densities tier 1 data.

Class	**Value (tC/Ha)**	**Uncertainty**	**Source**	**Remark**
Cropland	4.7	75%	Table 5.9: Chapter 5 of 2019 refinement	This is a value for annual croplands, 1 year after conversion. Most conservative approach.
Grassland	4.4	75%	Table 6.4: Chapter 6 of 2006	Total biomass is presented as 8.7 t/Ha, no refinement in 2019. This is a post-conversion value for tropical dry regions, i.e., the closest possible match.
Settlements	0	0	No Data	To be conservative, the extreme case scenario of 0 (zero) residual biomass is assumed.
Wetlands	0	0	No Data	To be conservative, the extreme case scenario of 0 (zero) residual biomass is assumed.
Other	0	0	No Data	To be conservative, the extreme case scenario of 0 (zero) residual biomass is assumed.

4.4.4. Emission factor calculations

The Emission factors for each REDD+ activity (Table 4.7. Emission factors for REDD+ activities.7) were calculated as the Forest class carbon density minus the post-conversion class carbon density. Uncertainty was propagated following Approach 1 of the IPCC 2006 Guidelines for National Greenhouse Gas Inventories Chapter 3 and the IPCC Good Practice Guidance for LULUCF Chapter 5, i.e., equation 4.9 below.

$$U_{total} = \frac{\sqrt{(U_1 * x_1)^2 + (U_2 * x_2)^2 + \cdots + (U_n * x_n)^2}}{|x_1 + x_2 + \cdots + x_n|} \quad [4.9]$$

Where:

U_{total} = the percentage uncertainty in the sum of the quantities (half the 95 percent confidence interval divided by the total (i.e., mean) and expressed as a percentage). This term 'uncertainty' is thus based upon the 95 percent confidence interval.

x_i *and* U_i = the uncertain quantities and the percentage uncertainties associated with them, respectively.

Table 4.7. Emission factors for REDD+ activities.

Activity	**Initial density**		**Post-conversion density**		**Emission Factor (tCO_2e/Ha)**	
	Mean (tCO_2e/Ha)	**Uncertainty at 95% CI**	**Mean (tCO_2e/Ha)**	**Uncertainty at 95% CI**	**Mean (tCO_2e)**	**Uncertainty at 95% CI**
Forest to Cropland	146.9	24.2 %	17.2	75 %	129.7	23.0 %
Forest Grassland	146.9	24.2 %	16.1	75 %	130.8	23.0 %
Forest to Settlement	146.9	24.2 %	0	-	146.9	24.2 %
Forest to Wetland	146.9	24.2 %	0	-	146.9	24.2 %
Forest to Other	146.9	24.2 %	0	-	146.9	24.2 %

5. FREL Calculation and Results

The FREL (Table 5.1) was calculated for each REDD+ activity and then summed up to obtain the total national FREL. The FREL for activity *i* was calculated based on the respective change area and emission factor (EF) using equation 5.1 below.

$$FREL_i = \text{Change Area}_{\text{Activity}_i} * EF_{Activity_i} \qquad [5.1]$$

Total FREL was then calculated using equation 5.2.

$$FREL_{total} = \sum_{i=1}^{n} FREL_i \qquad [5.2]$$

The uncertainty of the FREL was obtained by combining the uncertainties of the Emission Factors and Activity Data using approach 1 of the earlier mentioned IPCC guidelines for combining uncertainties when multiplying, i.e., equation 5.3 below.

$$U_{total} = \sqrt{U_1^2 + {U_2}^2 + \cdots + U_n^2} \qquad [5.3]$$

Where:

U_{total} = the percentage uncertainty in the product of the quantities (half the 95 percent confidence interval divided by the total and expressed as a percentage);

U_i = the percentage uncertainties associated with each of the quantities.

Table 5.1. Zimbabwe Forest Reference Emission Level.

Activity	**Emissions (tCO_2e)**	**Uncertainty @ 95 % CI**
Forest to Cropland	27,480,954.3	33.5
Forest to Grassland	0	-
Forest to Settlement	2,073,843.6	82.2
Forest to Wetland	0	-
Forest to Other	1,571,387.8	72.2
Total FREL	**31,126,185.7**	**30.3**

The total emissions over the 6 years were, therefore, 31,126,185.7 tCO_2e ± 30.3 %, which gives a FREL value of **5,187,697.6 ± 1,573,976.3 tCO_2e** per year.

6. Updating Frequency

The current FREL is technically valid for the projected 6-year period of 2022-2027 (inclusive). However, as explained in some sections, Zimbabwe is undergoing or has planned various improvements in the collection and processing of the data that make the building blocks for a FREL. Therefore, Zimbabwe expects to submit at least one updated/modified FREL before the 6 years lapse. The frequency of the updating will depend on the following main factors:

1. Availability of data for additional pools (deadwood, litter, and SOC).
2. Improvements in data collection and analysis, especially regarding the NFI program.
3. Launch of a Jurisdictional REDD+ program.
4. Need to align with any results-based financing programs or achievement of global mitigation goals.
5. Availability of reliable methods of quantifying degradation emission factors.

7. Expected Future Improvements

As emphasized in various sections, the submission of this FREL was the first stage in a stepwise approach that would see the submission of updated FRELs based on country needs, local and international goals, and improvement in the overall technical approach. Zimbabwe will be continuously working on the following components and submit an updated FREL when significant progress has been achieved in at least one of them, while also taking into consideration the factors mentioned above.

Forest degradation

The current FREL excluded the forest degradation REDD+ activity due to a lack of complete data. While SOPs are already developed and tested for the identification of forest degradation during activity data analysis, the corresponding residual carbon density data is not available. The Activity Data assessment process revealed that forest degradation occurred at a rate of 13,834.5 Ha per year, which accounts for 31 % of the emissions-related activities (deforestation + degradation). Forest degradation, is, therefore, an important source of emissions that the government of Zimbabwe is prioritizing as an area of improvement in FREL reporting. Parallel to the improvement of the NFI program to properly stratify and measure degradation carbon stocks, the current activity data analysis SOPs will also be refined based on past experience to minimize uncertainty in quantifying the degradation-related emissions. Once these improvements are made, the forest degradation activity will be included in future FREL submissions.

Emission factors

The NFI program will be improved to include sampling of all land use/ land cover strata. This will enable the calculation of inventory-based residual carbon densities for all non-forest land use classes. The plan is to match the activity data analyses sample grid to the NFI program sample grid to ensure data coherence. The use of tier 2 data is expected to minimize uncertainty compared to the use of tier 1 data (IPCC default) for all non-forest land use classes in this FREL. Another improvement expected in the NFI program is the development of local generic allometric equations for modeling aboveground biomass. When such models are available, carbon stocks will be calculated based on these rather than tier 1 models as in this FREL. The current NFI program uses only one class for forested land. Future planned improvements include the stratification of forest into intact forest and degraded forest to enable an accurate estimation of carbon densities in degraded forests.

Pools

The planned improvements in the NFI program include accurate collection and processing of deadwood carbon stocks. The litter pool is less likely going to be included in the near-future improvements of the NFI program, thus once deadwood data is available, default values may be evaluated and considered for that pool only. This is expected to result in a lower uncertainty than using tier 1 data for both deadwood and litter.

Removals (enhancement, sustainable forest management, and forest conservation)

Zimbabwe acknowledges that as the national efforts to promote forest conservation continue to yield results, recovery, and regrowth of forests will result in significant carbon removals. However, the country lacks the capacity to accurately collect and analyze this data at the national level. While not certain about timelines, efforts will be made to further improve the NFI program to include an accurate assessment of removals.

Emissions from fire

Wildfires are a common occurrence in Zimbabwe during the dry season. However, the dominant miombo woodlands are considered to be fire-shaped and some literature suggests that as long as the fires are sub-crown and non-destructive, the regrowth that comes soon after fire immediately offsets the emissions released during the fires. It is, therefore, not known yet whether fire contributes significant net emissions for it to be included in the FREL. The DNA will continue its collaboration with relevant parastatals such as the Environmental Management Agency (EMA) and academic and research institutes to improve the country’s knowledge regarding fire emissions. When conclusive research results are available, a decision will be made on whether or not to include fire emissions in future FRELs.

Activity data analyses

Zimbabwe will keep building capacity in remote sensing data analysis to improve the forest cover dynamics mapping in the historic reference period and detection of REDD+ activities. Based on the current experience, areas of improvement noted are access to higher-resolution imagery and the collection of more field-based training and validation data points.

QAQC

For all subsequent FREL submissions, Zimbabwe will perform a thorough QAQC exercise to further refine both the identification of REDD+ activities and the estimation of land use change class areas.

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9. Appendices

9.1. Forest Degradation

Forest Degradation is defined as the reduction in crown cover, i.e. transition from dense forest to moderate and open canopy cover forest or from moderate canopy cover forest to open canopy cover forest due to natural or anthropogenic disturbances. However, while degradation areas were initially quantified during the activity data analyses, the corresponding carbon densities data was not available from the NFI data. Therefore, for this FREL, an area estimate for forest degradation during the historic reference period was calculated as 83,006.8 Ha ± 42.8 % uncertainty at the 95% confidence interval. The same, or improved activity data analysis procedure will be used to calculate the area estimate for the next edition of the FREL. The improvements planned for the NFI program include collecting carbon stocks in forest areas stratified as intact and degraded. Therefore, in the upcoming FREL edition, emissions factors are expected to be available for this activity such that Zimbabwe will be able to fully report the emissions associated with degradation.

9.2. FAO Forest change probability mapping procedure

Rough workflow for Zimbabwe

1. Create SEPAL Planet mosaic for 2016 (start: 31.12.2015, end: 1.1.2017)
2. Create SEPAL Planet mosaic for 2022 (start: 31.12.2021, end: 1.1.2023)
    3. Create a SEPAL mask recipe with Hansen composite with Planet data as a mask for 2016
a. Input →EE asset: ee.Image('UMD/hansen/global_forest_change_2016_v1_4')
    b. Planet Sepal recipe as mask
    4. Create a mask recipe with Hansen composite and Planet data as mask for 2022 a. Input
→EE asset: ee.Image('UMD/hansen/global_forest_change_2022_v1_10')
    5. Create ALOS composites for 2016 and 2022 using this script:
https://code.earthengine.google.com/58ae9d002cb83d53e4f794c648d983f2
ALL INPUT DATA CAN BE VISUALIZED HERE:
https://code.earthengine.google.com/9323acf937243b215fda1d8cb2944c91
    6. Run SEPAL Classification recipe for 2016 with: a. Sepal recipe Planet 2016
    b. Sepal recipe Masked Hansen 2016
    c. ALOS EE Asset 2016
    d. Legend to 0 and 1 (Non-Forest and Forest)
    e. Stable FNF training data
    f. `1500 trees in RF`
    7. Run SEPAL Classification recipe for 2022 with: a. Sepal recipe Planet 2022
    b. Sepal recipe Masked Hansen 2022
    c. ALOS EE Asset 2022
    d. Legend to 0 and 1 (Non-Forest and Forest)
    e. Stable FNF training data
    f. `1500 trees in RF`

`users/andreasvollrath/Zimbabwe/training_091123_stable`
NOTE: Classification recipe is buggy, just go through
`users/andreasvollrath/Zimbabwe/training_091123_stable`
the steps and export all layers, BE AWARE IT WONT SAVE THE RECIPE
8. SELECTION OF TRAINING DATA POINTS FOR REVISION
https://code.earthengine.google.com/1f0f16e4fddb9faabb95fdbe3e06c83d
9. REPEAT Steps 6 & 7 with revised points as training data and export the outputs with all layers
10. Create the absolute FNF probability difference layer and the maximum FNF probability layer and sample both + CCI biomass layer for all of the 240k points as in this script and export the samples with the probs sampled:
11. https://code.earthengine.google.com/e596551337ab94da3645b4c55798f529
12. Final step is to filter down and select the final samples to select the reference samples for data collection. The script used for stratification can be assed here:
https://code.earthengine.google.com/477b12056ea1630752f22651a09ced51

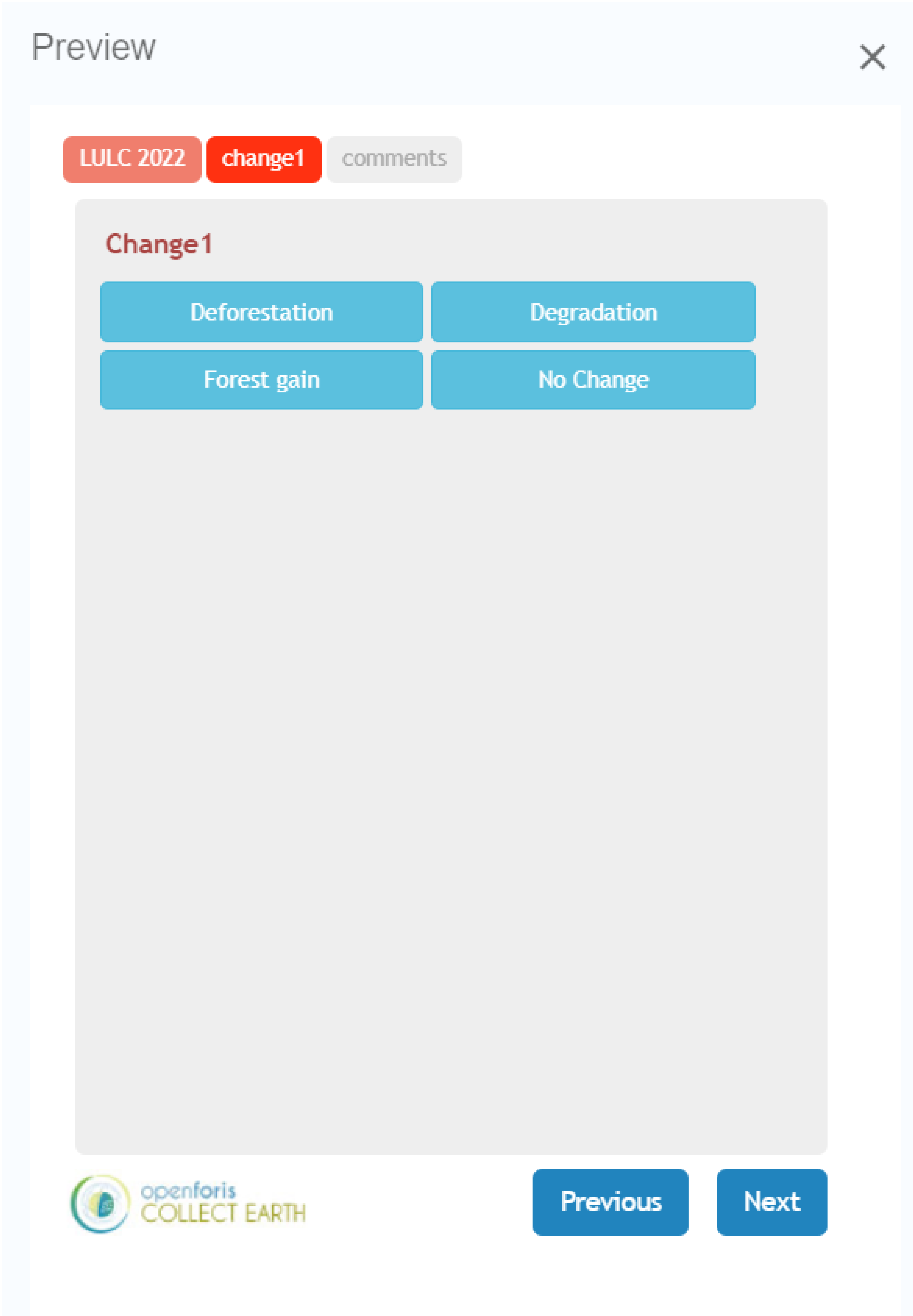
9.3. Activity Data collection cards

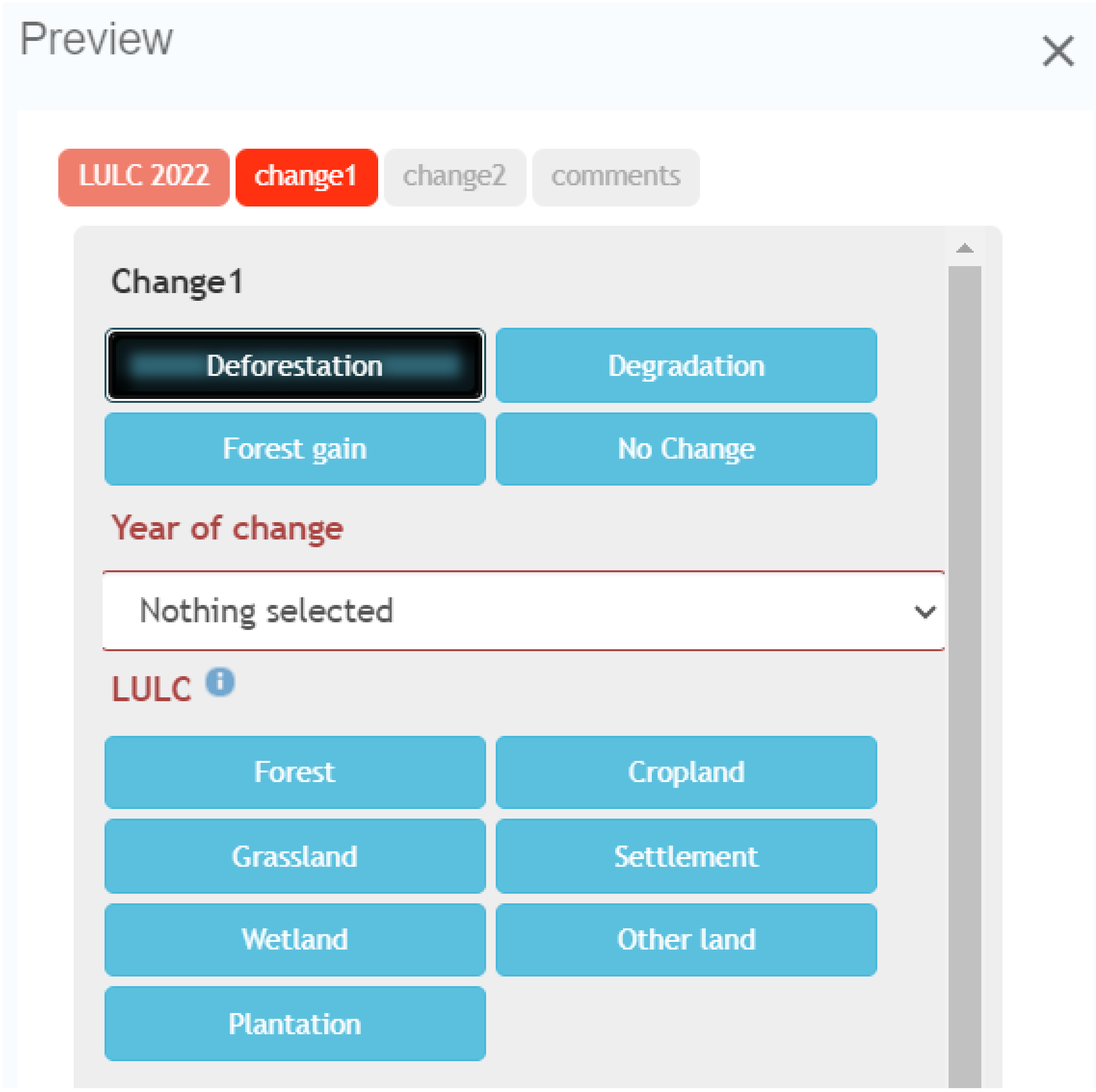
Reference Data collection survey card

Data is collected using collect earth open Foris tool.

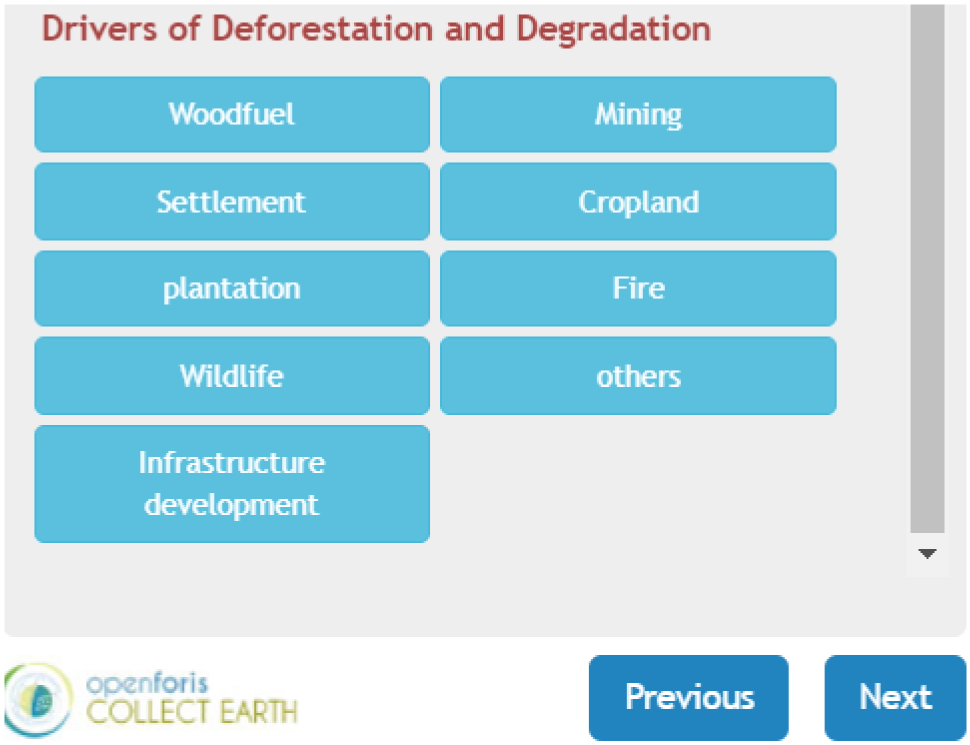
We are collecting data starting from 2022 LULC classes using IPCC classes but collecting information on plantations as well separately.

So going back from 2022 to up to 2000 for data collection, and recording multiple changes. This is to align with the FRA project. Although we will only use 2016- 2021 information for FREL.


Preview
LULC 2022
change1
comments
Change1
Deforestation
Degradation
Forest gain
No Change
openforis
COLLECT EARTH
Previous
Next



In case of deforestation interpreter will record the year of change and LULC information for that year and second question also appears on drivers of deforestation and forest degradation


Drivers of Deforestation and Degradation
Woodfuel
Mining
Settlement
Cropland
plantation
Fire
Wildlife
others
Infrastructure development
openforis
COLLECT EARTH
Previous
Next


Drivers of Deforestation and Degradation
Woodfuel
Mining
Settlement
Cropland
plantation
Fire
Wildlife
others
Infrastructure development
Species
Elephant
Others
openforis COLLECT EARTH
Previous
Next

9.4.Activity Data response design and explanatory variables

Response Design and Explanatory variables Zimbabwe Activity Data

IPCC land cover classes [10]

Forestland

This category includes all land with woody vegetation consistent with thresholds used to define forest land in the national GHG inventory, sub-divided into managed and unmanaged, and also by ecosystem type as specified in the IPCC Guidelines3. It also includes systems with vegetation that currently fall below, but are expected to exceed, the threshold of the forest land category.

Land spanning more t**han 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent,** or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.

Explanatory variables

- It does not include land that is predominantly under agricultural or urban land use. Forest is determined both by the presence of trees and the absence of other predominant land uses.
- The trees should be able to reach a minimum height of 5 meters in situ.
- Is forest management site considered as forest, even unstocked.
- Includes forest roads, firebreaks, and other small open areas; forest in national parks, nature reserves, and other protected areas such as those of specific environmental, scientific, historical, cultural, or spiritual interest.
- It **includes** the plantation for restoration purposes. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 10 percent or tree height of 5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes, but which are expected to revert to forest." (FAO/UNEP, 1999)
- **Excludes** tree stands in **agricultural production systems**, such as fruit tree plantations, oil palm plantations, olive orchards, and agroforestry systems when crops are grown under tree cover.
- Note: Some agroforestry systems such as the **"Taungya" system** where crops are grown only during the first years of the forest rotation should be classified as forest.

[10] https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp2/Chp2_Land_Areas.pdf

<u>Cropland</u>

This category includes arable and tillage land, and agro-forestry systems where vegetation falls below the thresholds used for the forest land category, consistent with the selection of national definitions.

<u>Explanatory variables</u>

- Includes arable and tillable land, rice fields, and agroforestry systems where the vegetation structure falls below the thresholds used for the Forest Land category and is not expected to exceed those thresholds later.
- Cropland includes all annual and perennial crops.
- Annual crops include cereals, oils seeds, vegetables, root crops and forages.
- Perennial crops in combination with herbaceous
- crops (e.g., agroforestry) or as orchards, vineyards and plantations such as cocoa, coffee, tea,
- coconut, bananas
- Arable land, which is normally used for cultivation of annual crops, but which is temporarily used for forage crops or
- grazing as part of an annual crop-pasture rotation (mixed system) is included under cropland.
- Fellow land with and without trees

<u>Grassland</u>

This category includes **rangelands and pastureland** that is not considered as cropland. It also includes systems with vegetation that fall below the **threshold used in the forest land category and are not expected to exceed (trees less than 5 meter in height)**, without human intervention, the threshold used in the forest land category. The category also includes **all grassland from wild lands to recreational areas** as well as **silvi-pastural systems**, subdivided into **managed and unmanaged** consistent with national definitions.

<u>Explanatory variables</u>

Grasslands can vary greatly in their degree and intensity of management, from extensively managed rangelands and savannahs – where animal stocking rates and fire regimes are the main management variables – to intensively managed (e.g. with fertilization, irrigation, species changes) continuous pasture and hay land.

- Grasslands generally have a vegetation dominated by **perennial grasses**, with **grazing as the predominant land use**, and are distinguished from "forest" by having a **tree canopy cover of less than** 10 percent.
- **Grasslands includes rangelands and pastureland that not considered Cropland including systems with woody vegetation** and other **<u>non-grass</u>**

vegetation such as herbs and shrubs (shrubs are tress where height is less than 5 meter).

Wetlands

This category includes land that is covered or **saturated by water for** all or part of the year (e.g., **peatland)** and that does not fall into the forest land, cropland, grassland or settlements categories. The category can be subdivided into managed and unmanaged according to national definitions. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged subdivisions.

Explanatory variables

- Guidance is restricted to **Managed Wetlands where the water table is artificially changed** (e.g., drained or raised) or wetlands created through human activity (i.e., damming a river)
- Reservoirs or impoundments, for energy production e.g., Dam
- irrigation, navigation, or recreation (Flooded Land)
- **All water bodies**, including seasonal water bodies, swamps.
- **Wetlands**
- **Natural or artificial ponds,**
- **Rivers, Lakes and streams, waterfalls**

Settlements

This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. This should be consistent with the selection of national definitions.

Explanatory variables

Settlements are defined includes **residential, transportation, commercial, and production (commercial, manufacturing) infrastructure of any size,** unless it is already included under other land-use categories.

- The land-use category Settlements includes soils, herbaceous perennial vegetation such as turf grass and garden plants, trees in rural settlements, homestead gardens and urban areas.
- Examples of settlements include land along **streets, roads in residential (rural and urban) and commercial lawns**, in **public and private gardens**, in **golf courses** and athletic fields, e.g., cricket field and in parks, provided such land is functionally or administratively associated with **cities, villages or other settlement types** and is not accounted for in another land-use category.

- Airports, factories

Other land

This category includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available. **Explanatory variables**

- Other Land includes **bare soil, rock, ice**, and all land areas that do not fall into any of the other five land-use categories.
- Other Land is often unmanaged, and in that case changes in carbon stocks and non-CO_2 emissions and removals are not estimated.
- Active Mine dump generally but also include the dumps if not active.

Plantation

- Includes commercial plantation as well, pine, eucalyptus and others.

Tree cover Forest: please add the tree cover percentage in case of Forest by counting sub sample in the plot.

Deforestation

- Forest land changed to non-forest land during 2000 – 2022.
- This includes both changes in land use:
- Tree cover percentage reduce to less than 10% even no land use change.
- Even percentage tree cover is above 10% but land use change is observed as a major activity.

Examples

- Forest land converted to plantation.
- Forest land converted to settlement.
- Forest land converted to cropland.
- 2016 Tree cover was 70% but in 2022 reduced to 7%, will be deforestation.
- 2018 was a forest and in 2022 converted to cropland but percentage tree cover is 12 %, will be deforestation.

Forest degradation

- Forest remains Forest.

- Usually defined as reduction in canopy cover but still have percentage of forest cover as of forest definition. Examples percentage of canopy cover is reduced to 30% in 2017 from 90% in 2016

Forest gain

- When Non-Forest land converted to Forest land.
- Please remember the forest definition criteria to classify it as a gain/increased.

9.5. Zimbabwe's FREL Improvement Plan

The table below presents Zimbabwe's proposed road map for FREL improvement, led by the Forestry Commission.

Thematic Area/ Component	Description of Activity	Justification of the Activity	Implementation Period (Duration)	Partner Organizations	Possible Funding source	Priority: High (H) Medium (M) Low (L)
Legal framework, Policies and strategies	Development of new or improvement of existing Legal Frameworks, Policies and Strategies	Ensuring that Zimbabwe's legal frameworks support sustainable forest management practices and facilitate the achievement of emission reduction targets and align with international commitments such as the Paris Agreement.	2 years	Ministry of Environment, Climate and Wildlife, EMA, ZimParks, ZELA, NGOs, CSOs, TPF, Academia	GoZ budget allocation, Climate finance mechanisms	H
Institutional arrangements	Strengthen institutional capacity for forest governance and coordination.	Enhancing coordination and oversight of forestry activities, including monitoring and reporting of emissions.	1 year	Ministry of Environment, Climate and Wildlife	GoZ, International development partners, Public-private partnerships	H
Activity Data (forests, soil and fire), emission factors, and research	1. Recalculate and validate deforestation rates for NC, BTR and FREL	To improve transparency, comparability and accuracy in reporting BTR, NC5 and FREL.	6 Months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H
	2.Stratification of forest by vegetation types	To develop emission factors (EF) that are specific for each vegetation type to improve accuracy of carbon stocks in live biomass	1 year	AFOLU working group	GoZ, International development partners, Public-private partnerships	H

Thematic Area/ Component	Description of Activity	Justification of the Activity	Implementation Period (Duration)	Partner Organizations	Possible Funding source	Priority: High (H) Medium (M) Low (L)
Activity Data (forests, soils and Fires) Emission factors and research	3. Classifying forests by degradation status.	To improve accuracy in estimating carbon stocks, change in degraded forests, and associated emission factors	18 Months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H
	4. Determining decay rates and carbon transfers in dead organic matter.	To improve accuracy in estimates of emissions/ removals in DOM	6 months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H
	5. Determining country-specific SOC stocks and dynamics	To improve our estimates of emissions/ removals in Soil Organic Matter.	6 months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H
	6. Generate country specific activity data on fire	To improve the accuracy of National activity data on Fires	6 Months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H
	7.Development of fire EF in different vegetation types	To improve accuracy in estimates of emissions due to Forest Fires	12 Months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H
	8. Collection of disaggregated Harvested Wood products data	To improve accuracy in estimates of removals and forest disturbances	12 Months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H
Technical Capacity	1. Acquire mechanized soil sampling survey and Lab equipment.	Increase efficiency and reduce labor costs	6 Months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H

Thematic Area/ Component	**Description of Activity**	**Justification of the Activity**	**Implementation Period (Duration)**	**Partner Organizations**	**Possible Funding source**	**Priority: High (H) Medium (M) Low (L)**
Technical Capacity	2.Acquire Drones and other forest inventory equipment	Reduce data collection costs & increase efficiency and accuracy	6 Months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H
	3.Development of country specific allometric equations	To increase accuracy by using locally developed equations as recommended by IPCCC guidelines	18 Months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H
	4.Development of applications including but not limited to tree identification apps	Reduce costs of ground truthing. Reduce human error	12 months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H
	5.Capacity building in geospatial tools including but not limited to Collect Earth.	To be able to apply advanced methodologies for data collection and improve accuracy and efficiency.	6 Months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H
	6.Development of a forest carbon Database and Geoportal	Safe data storage, archiving and efficient data sharing	7 Months	AFOLU working group	GoZ, International development partners, Public-private partnerships	H