Annex 5: ER Monitoring Report (ER-MR) on the area outside the scope of Zambézia Integrated Landscape Management Program (ZILMP)

Summary

The purpose of the present document is to present the Emissions Reductions Monitoring Report (ER-MR) on the area outside the scope of Zambézia Integrated Landscape Management Program (ZILMP), reporting results for 2018. The estimates presented here were generated considering carbon dioxide (CO_2) as the only greenhouse gas, the above ground biomass (AGB) and below ground biomass (BGB) as the only carbon sinks, and the reducing emissions from deforestation as the only REDD+ activity. A **Forest Reference Emission Level** (FREL) was constructed and estimated at **7,935,258.05 tonnes of carbon dioxide equivalents per year** (tCO2e*yr-1) from 25,268.90 hectares per year (ha*yr-1) of deforested natural forest land, considering a period of 11 years, from January 2005 to December 2015. For the **monitoring period** in 2018, the carbon emissions from deforestation were estimated at **1,736,005.55 tCO_2e**, reflecting an **estimated emission reductions of 3,906,378.29 tCO_2e** based on agreed reporting period in the scope of ERPA signature for ZILMP.

Contents

1 INTRODUCTION

This report was prepared as part of the Government's commitment to monitor and report in parallel the annual emissions reduction in the area outside the scope of Zambézia Integrated Landscapes Management Program (ZILMP) within the Zambézia province under the Emission Reductions Purchase Agreement (ERPA) signature.

The present report mentions reduced emissions in 2018, presenting six essential sections for a better understanding of the process of its estimates. Each section is described below.

2 CARBON POOLS, SOURCES AND SINKS

2.1 Description of Sources and Sinks selected

Sources/Sinks	Included?
Emissions from deforestation	Yes
Emissions from forest degradation	No
Enhancement of carbon stocks	No
Sustainable management of forests	No
Conservation of carbon stocks	No

2.2 Description of carbon pools and greenhouse gases selected

Carbon Pools	Selected?
Above Ground Biomass (AGB)	Yes
Below Ground Biomass (BGB)	Yes
Biomass in non-woody vegetation	No
Dead organic matter	No
Soil Organic Carbon (SOC)	No

GHG	Selected?
CO_2	Yes
CH_4	No
N_2O	No

3 REFERENCE LEVEL

3.1 Reference Period

The reference period is from 2005 – 2015 (11 years).

3.2 Forest definition used in the construction of the Reference Level

According to the national REDD+ strategy and to the Final Report on Forest Definition (Falcão and Noa, 2016) approved by MITADER in November 2016, forest in Mozambique is defined as followed: **minimum area of 1 ha, minimum height at maturity of 3 m and minimum tree cover of 30%**.

The previous GHG inventories used the previous forest definition of Mozambique (minimum area of 0.5 ha, minimum height of 5m and minimum tree cover of 10%). However, future GHG inventories will use the updated forest definition.

3.3 Average annual historical emissions over the Reference Period

3.3.1 Description of method used for calculating the average annual historical emissions over the Reference Period

The UNFCCC does not give any directives with regards to the reference period for the RL. However, the Forest Carbon Partnership Facility (FCPF) have specific guidelines, setting a minimum of 10 years and a maximum of 15 years. The chosen period for the construction of the RL is from 2005 to 2015, 11 years.

In accordance with the UNFCCC decisions, the method used to assess emissions is the one described in IPCC (2006) for Land (Forest land in the present case) converted to other land use (e.g., croplands, grasslands, etc.) consisting on the multiplication of activity data – area of land converted from forest land to other land (e.g., cropland or grassland in the present case) – by emission factors – difference of carbon stocks before and after deforestation – as presented on the following equations. The data used for the present document are Tier 2 (country specific data or country level estimates) or Tier 3 (data specifically produced for the ER Program) when possible. Activity data are produced on the reference period with spatially explicit method based on available satellites images. Emissions factors are derived from literature or forest inventory in the accounting area.

In compliance with criterion 13 of FCPF MF (FCPF, 2016) that specifies that RL should not exceed the average annual historical emissions, different activity data of the reference period will be averaged to produce annual deforestation areas over the whole period.

As analysis is done over the reference period, long term (10 years) changes (increase or decrease) of carbon stocks on deforested areas (land converted to another land use) are considered instead of annual increase or decrease - see the **Equation 2**.

Gross emissions of the RL from deforestation over the Reference Period ($\mathrm{RL_{RP}}$) are estimated as the sum of annual change in total biomass carbon stocks ($\Delta \mathrm{C_{B_t}}$) during the reference period as shown in the equation below.

$$RL_{RP} = \frac{\sum_{t}^{RP} \Delta C_{B_t}}{RP}$$ ***Equation 1***

Where:

ΔC_{B_t}	=	Annual change in total biomass carbon stocks at year *t; tC*year^{-1};*
RP	=	Reference period, *years.*

Following the 2006 IPCC Guidelines, the annual change in total biomass carbon stocks forest land converted to other land-use category *(*ΔC_{B_t}*)* would be estimated through the following equation:

$$\Delta C_{B_t} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L \qquad \textbf{\textit{Equation 2}}$$

Where:

ΔC_{B_t}	Annual change of total biomass carbon stocks during the period, in tC per year;
ΔC_G	Annual increase in carbon stocks in biomass due to growth on land converted to another land-use category, in tC per hectare and year;
$\Delta C_{CONVERSION}$	Initial change in carbon stocks in biomass on land converted to other land-use category, in tC per hectare and year; and
ΔC_L	Annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tC per hectare and year.

Following the recommendations set in chapter 2.2.1 of the GFOI Methods Guidance Document for applying IPCC Guidelines and guidance in the context of REDD+[1], the above equation will be simplified and it will be assumed that:

- The annual change in total biomass carbon stocks *(*ΔC_B*)* is equal to the initial change in carbon stocks *(*$\Delta C_{CONVERSION}$*)*;

Considering equation 2.16 of the 2006 IPCC GL for estimating *(*$\Delta C_{CONVERSION}$*)* the change of biomass carbon stocks could be expressed with the following equation:

$$\Delta C_{B_t} = \sum_{j,i} \left(B_{Before,j} - B_{After,i}\right) x\ CF\ x \frac{44}{12} \times A(j,i)_{RP} \qquad \textbf{\textit{Equation 3}}$$

Where:

$A(j,i)_{RP}$ Area converted/transited from forest type *j* to non-forest type *i* during the Reference Period, in *hectares per year*. In this case, three forest land conversions are possible:

- (Semi-)deciduous forest to Non-forest type *i*;
- (Semi-)evergreen forest to Non-forest type *i*; and
- Mangrove forest to Non-forest type *i*.

Five types of non-forest land are considered:

- Cropland (C);
- Grassland (P);
- Wetland (A);
- Settlement (U); and
- Other lands (O).

<u>Some of the technical corrections applied pertain this parameter:</u>

- The activity data was corrected by correcting two mistakes that were identified, one related to the length of the period of analysis (10 years instead of 11 years)
- The final ERPD applied a post-deforestation carbon density for each of the forest types, whereas in the technically corrected RL the five non-forest IPCC Land Use categories have been used instead.

[1] https://www.reddcompass.org/documents/184/0/MGD2.0_English/c2061b53-79c0-4606-859f-ccf6c8cc6a83

	The description of this parameter may be found in *Annex 4 – Section Activity data and emission factors used for calculating the average annual historical emissions over the Reference Period*
$B_{Before,j}$	Total biomass of forest type *j* before conversion/transition, in tons of dry matter per ha. This is equal to the sum of aboveground ($AGB_{Before,j}$) and belowground biomass ($BGB_{Before,j}$) and it is defined for each forest type.
$B_{After,i}$	Total biomass of non-forest type *i* after conversion, in *tons dry matter per ha*. This is equal to the sum of aboveground ($AGB_{After,i}$) and belowground biomass ($BGB_{After,i}$) and it is defined for each of the five non-forest IPCC Land Use categories.
CF	Carbon fraction of dry matter in tC per ton dry matter. The value used is: • **0.47** is the default for (sub)tropical forest as per IPCC AFOLU guidelines 2006, Table 4.3.
$44/12$	Conversion of C to CO_2

3.3.2 Activity data and emission factors used for calculating the average annual historical emissions over the Reference Period

Activity data

Parameter:	*A(j,i)$_{RP}$*
Description:	Area converted from forest type *j* to non-forest type *i* during the reference period.
Data unit:	hectare per year.
Source of data and description of measurement/calculation methods and procedures applied:	***i. Approach and source*** Activity data for deforestation were obtained from an annual historical time series analysis of land use, land-use change and forestry (LULUCF) carried out by five trained operators in approximately 98 effective working days (4.4 months), for the period of 2001 – 2016 across the country, using the Collect Earth Open tool. Activity data have been generated following IPCC Approach 3 for representing the activity data as described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 4, Chapter 3, Section 3.13), i.e., using spatially-explicit observations of land-use categories and land-use conversions over time across the country, derived from sampling of geographically located points. The result was forest cover data for 2016 and forest cover change data for every year from 2001 to 2016. The period of AD analysis from 2005 to 2015 (11 years) considered for the ER in the area outside the scope of ZILMP within the Zambézia province, could be adapted within the general period 2001 – 2016 with little effort, due to the operators collecting the date of the LULC change. ***ii. Sampling design*** A systematic 4 x 4 km grid consisting of a total of 48, 894 sampling points was established at a national level to generate the historical activity data for the entire area of the country using high and medium resolution imagery, which is the same grid used to allocate the NFI clusters from the Stratified Random Sampling design. At jurisdictional level, this corresponds to 2,984 points being interpreted. Each sampling point was visually assessed

and its information was collected and entered in a complete database on LULC changes at the national level.

iii. Response design

Spatial sampling unit

The spatial sampling unit from each point was defined as a point with a spatial support consisting of a 100m x 100m plot (1 ha), where an internal grid of 5 x 5 points (20m x 20m grid) is overlapped. Each point from the internal grid has a weight coverage of 4% (Figure 1).

Figure 1: Spatial sampling unit

Source of reference data

The sampling approach for historical AD calculation based on the regular National 4 x 4 km grid has been designed and conducted using the high and medium resolution images repository available through Google Earth and Earth Engine as a visual assessment exercise. These imagery with digital forms (Figure 2) designed to collect the LULCC information on the points of the grid are automatically accessible through the Collect Earth tool (www.openforis.org) along with scripts accessible through Earth Engine code that facilitate vegetation type's interpretation (e.g. MODIS or Landsat NDVI time series). Each point of the grid is photo-interpreted thanks to Collect Earth tool and the year and type of changes are also collected.

The use of various scripts programmed on Earth Engine Code facilitates the interpretation of the vegetation type and the determination of LULC changes. Specifically, the MOD13Q1 (NDVI 16-day Global Modis 250 m) graphic from 2001-2016, most recent Sentinel-2 image, most recent Landsat-8 pan sharpened image, Landsat-7 pan sharpened image (2000, 2004, 2008, 2012), etc.

The completeness of the series is guaranteed using RS products from medium resolution imagery repositories from 2001 (e.g. Annual TOA Reflectance Composite, Annual NDVI Composite, Annual EVI Composite, Annual Greenest-Pixel TOA Reflectance Composite, etc. from Landsat 5 TM) and the most recent Sentinel-2 image from 2016. In this way, a temporal analysis of LULC changes has been completed for each sampling point of the national 4 x 4 km grid (48,894 records).

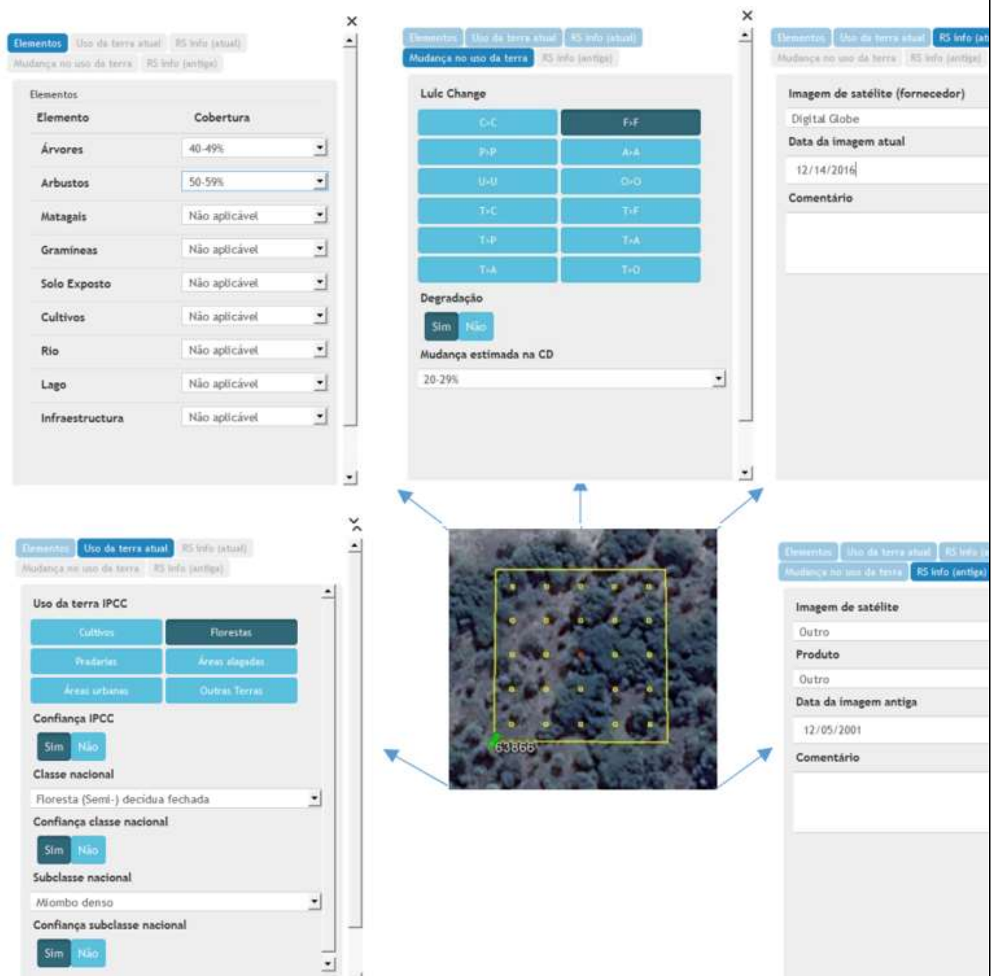

Figure 2: LULCCF detection using Collect Earth Tool (www.openforis.org). Digital forms designed with Collect Tool.

<u>Reference labelling protocol</u>

The activity data was generated considering the national land use and land cover classification system, which reflects the six broad IPCC Land Use categories. A set of hierarchical rules were established and used to determine the LULCCF category based on a certain percentage and taking into account the national forest definition as well (Figure 3). A single land use class is easier to classify, but it becomes challenging when there is a combination of two or more land use classes within the area of interest. Thus, this is where the hierarchical rules are important to determine the land use. Any sampling unit that has 30% of tree canopy cover is considered a forest, according to the national forest definition, even if it has more than 20% of settlements, crops or other land use, the forest has priority. In the case the sampling unit was classified as forest land and different forest types were present in the sampling unit, a majority rule was used in this case, i.e. the largest forest class is the winner.

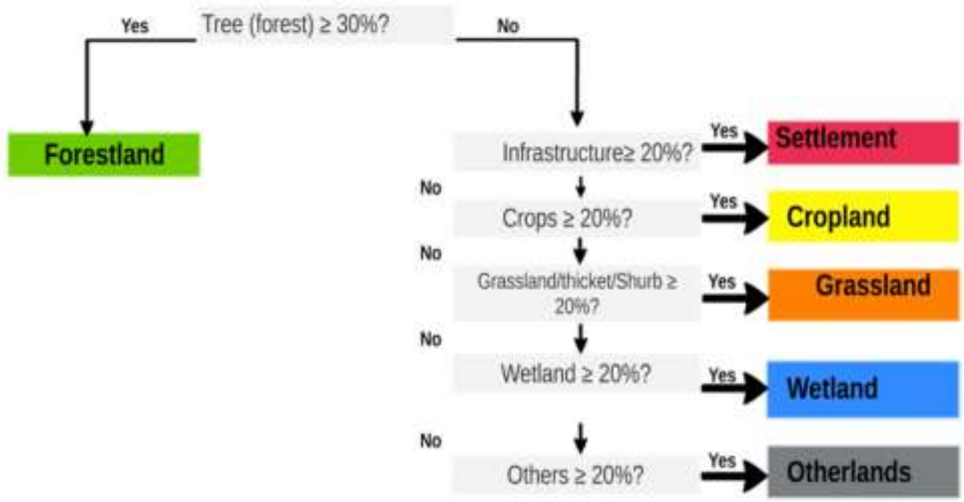

Figure 3: Decision tree for the attribution of the LULCCF category based on the percentage cover of the elements present in the sampling unit of 1 ha.

iv. Analysis

The estimation of the areas corresponding to a certain category changes from a forest type to a non-forest type in the framework of this systematic sampling approach was based on assessments of area proportions. According to 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 4, Chapter 3, Section 3.33), the proportion of each land-use or land-use change category is calculated by dividing the number of points located in the specific category by the total number of points, and area estimates for each land-use or land-use change category are obtained by multiplying the proportion of each category by the total area of interest, in this case, the area outside the scope of ZILMP within the Zambézia province.

$$A_i = p_i \times A$$ *Equation 4*

Where:

A_i	Area estimate on forest type *j* converted to non-forest type *i;* hectare
p_i	Proportion of points on forest type *j* converted to non-forest type *i;* dimensionles
A	Total area of interest; hectare

$$p_i = \frac{n_i}{N}$$ *Equation 5*

Where:

n_i	Number of points on forest type *j* converted to non-forest type *i;* number
N	Total number of points; number

The standard error (ha) of an area estimate was obtained as (2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Chapter 3, Section 3.33):

$$e_i = A_i \times \sqrt{\frac{p_i \times (1 - p_i)}{N - 1}}$$ *Equation 6*

<table>
<tr><td></td><td>Where:

A Area of interest, ha.
p_i Proportion of points on land use change category i, dimensionless.
n Number of sampling units, number.

The 90% confidence interval for A_i, the estimated area of land-use category i, was given approximately by ±1.64 times the standard error.</td></tr>
<tr><td>Value applied</td><td><table>
<tr><td>Semi-deciduous forest to cropland</td><td>17,505.56</td></tr>
<tr><td>Semi-deciduous forest to grassland</td><td>2,435.56</td></tr>
<tr><td>Semi-deciduous forest to other lands</td><td>0.00</td></tr>
<tr><td>Evergreen forest to cropland</td><td>4,566.67</td></tr>
<tr><td>Evergreen forest to grassland</td><td>152.22</td></tr>
<tr><td>Evergreen forest to other lands</td><td>152.22</td></tr>
<tr><td>Mangrove forest to cropland</td><td>0.00</td></tr>
<tr><td>Mangrove forest to grassland</td><td>152.22</td></tr>
<tr><td>Mangrove forest to other lands</td><td>304.44</td></tr>
</table></td></tr>
<tr><td>QA/QC procedures applied:</td><td>Quality Control consisted in having a team of 5 technicians with experience in forests and remote sensing, all trained together by an MRV specialist. The team worked in the same office, and discussed any classification issues with each other.

Quality Assurance was conducted using the SAIKU extension of Collect Earth. This tool allows the detection of whether:
i) Data point was not filled
ii) The class assigned followed the classification hierarchy, based on the % of individual element cover
iii) Year of the Old image/Change image was less than the current image
iv) Change classes are consistent with previous and current classes
v) Open and closed forest was correctly classified, based on the 30% (open) and 65% (closed) cover threshold

In the case of any error being detected, the ID of the data point was registered and the user performed the necessary corrections.</td></tr>
<tr><td>Uncertainty associated with this parameter:</td><td><table>
<tr><th>Category change</th><th>Uncertainty estimate (confidence interval at 95%)</th></tr>
<tr><td>Semi-deciduous forest to cropland</td><td>17.92%</td></tr>
<tr><td>Semi-deciduous forest to grassland</td><td>48.88%</td></tr>
<tr><td>Semi-deciduous forest to other lands</td><td>-</td></tr>
<tr><td>Evergreen forest to cropland</td><td>35.61%</td></tr>
<tr><td>Evergreen forest to grassland</td><td>196.00%</td></tr>
<tr><td>Evergreen forest to other lands</td><td>196.00%</td></tr>
<tr><td>Mangrove forest to cropland</td><td>-</td></tr>
<tr><td>Mangrove forest to grassland</td><td>196.00%</td></tr>
<tr><td>Mangrove forest to other lands</td><td>138.57%</td></tr>
</table></td></tr>
</table>

Any comment:	

Emission factors

Parameter:	$AGB_{before,j}$
Description:	Aboveground biomass of forest type *j* before conversion,
Data unit:	tons of dry matter per ha
Source of data or description of the method for developing the data including the spatial level of the data (local, regional, national, international):	The data used for the present document are Tier 2 (country specific data or country level estimates or locally derived estimates) and they were sourced from the NFI (for deciduous and evergreen forests) or for Mangrove forests. For semi-deciduous and evergreen forest, data are from the Zambézia Forest Inventory. It includes data that was collected in Zambézia province during the NFI, in 2017 and 2018. The following methods were used from the sampling design to estimation: ***i. Sampling design*** Carbon stocks before conversion for deciduous and evergreen forests were estimated using data from the National Forest Inventory sample units that were located in Zambézia province. The sample units for surveying carbon stocks were allocated using restricted stratified random sampling, using 4 * 4 km systematic grid superimposed on the agro-ecological zoning map, and stratified among the 4 forest types (semi-deciduous forest, semi-evergreen forest, Mopane and Mecrusse forest), of which only semi-deciduous forest and semi-evergreen forest occur in Zambézia province. The total number of sample units was determined using the optimal allocation (assuming a maximum error of 10% for the total volume, and 5% of confidence level). Proportional allocation was used to determine the number of sample units per stratum (Husch, Beers, and Kershaw 2003). For Zambézia province, 128 clusters (512 plots) were distributed between the two forest types. The cluster was used as a sampling unit, and each cluster has 4 plots of 0.1 ha (20 * 50 m), where each plot was divided into 4 sub-plots of 0.025 ha (10 * 25 m) (Figure 4).

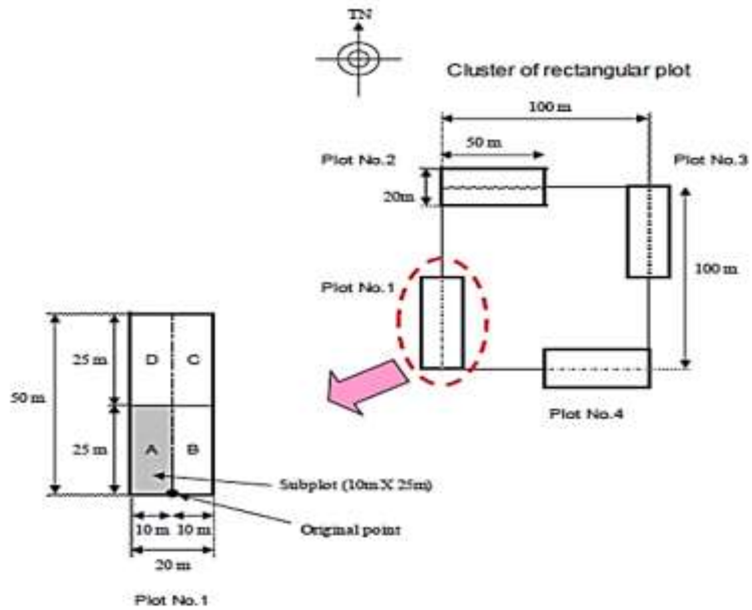

Figure 4: Design of each cluster used in the National Forest Inventory.

ii. Data collection

The plots were used for data collection of adult trees (dbh≥10cm), and the subplots "A" were used for data collection of established regeneration trees (10cm> dbh≥ 5 cm), which were included in the calculation of the carbon stocks. Data collected in the plots and subplots included tree information (dbh, scientific name, total and commercial height, stem quality), soil, forest type (this information was used to validate the information from agro-ecological zoning map), and other important information. Tree data were used to estimate above ground biomass (AGB) and below ground biomass (BGB).

The NFI did not cover Mangrove forests, so, data from the literature was used. For other strata, data from literature were also used.

Details of data collection can be find at https://www.fnds.gov.mz/mrv/index.php/documentos/guioes/35-directrizes-do-inventario-florestal-nacional/file .

iii. Prediction at plot level

Above ground biomass (AGB) and below ground biomass (BGB) were estimated using a series of allometric equations adjusted for ecosystems or tree species similar to those in the Zambézia province (Table 1), and this equation was applied at tree level.

The use of the equations meant, applying allometric equations of the specific species (*Millettia stuhlmannii* taub., *Pterocarpus angolensis DC., Afzelia quanzensis* Welw.) in all trees of these species to estimate AGB, regardless of forest types; The allometric equation of the semi-deciduous forest was applied for all trees of this forest type (except the above species), as well as in all trees of the species *Brachystegia spiciformis* Benth., and *Julbernardia globiflora (Benth.) Troupin* to estimate AGB and BGB, because they were the main species used to adjust this equation in this forest type. The equations of the semi-evergreen forest were applied in all remaining trees of this forest type to estimate AGB; and apply the semi-deciduous forest equation in all trees to estimate the BGB in this forest type (including species mentioned above in other forest type), and apply factor 0.28 (shoot ratio) to estimate the BGB of the semi-evergreen forest.

Table 1: List of allometric equations used to estimate above and below biomass

Stratum	Forest type or species	Above-ground biomass (AGB) [kg]	Below-ground biomass (BGB) [kg]
Semi-deciduous forest	Semi-deciduous forest (open and closed)	$\hat{Y} = 0.0763 * DAP^{2.2046} * H^{0.4918}$	$\hat{Y} = 0.1766 * DAP^{1.7844} * H^{0.3434}$
		Author: Mugasha *et al.* (2013)	Author: Mugasha *et al.* (2013)
	Millettia stuhlmannii taub.	$\hat{Y} = 5.7332 * DAP^{1.4567}$	$\hat{Y} = 0.1766 * DAP^{1.7844} * H^{0.3434}$
		Author: Mate *et al.* (2014)	Author: Mugasha *et al.* (2013)
	Pterocarpus angolensis DC.	$\hat{Y} = 0.2201 * DAP^{2.1574}$	$\hat{Y} = 0.1766 * DAP^{1.7844} * H^{0.3434}$
		Author: Mate *et al.* (2014)	Author: Mugasha *et al.* (2013)
	Afzelia quanzensis Welw.	$\hat{Y} = 3.1256 * DAP^{1.5833}$	$\hat{Y} = 0.1766 * DAP^{1.7844} * H^{0.3434}$
		Author: Mate *et al.* (2014)	Author: Mugasha *et al.* (2013)
Evergreen forest	Evergreen forest (open and closed)	$\hat{Y} = \exp(-2.289 + 2.649\ln(DAP) - 0.021(\ln(DAP))^2)$	$\hat{Y} = AGB * R/S$; R/S= 0.28
		Author: IPCC (2003)	Author: Mokany *et al.* (2006)
	Evergreen mountain forest (open and closed)	$\hat{Y} = 0.0613*DAP2.7133$	$\hat{Y} = AGB * R/S$; R/S= 0.29
		Author: Lisboa *et al.* (2018)	Author: Mokany *et al.* (2006)
	Millettia stuhlmannii taub.	$\hat{Y} = 5.7332 * DAP^{1.4567}$	$\hat{Y} = 0.1766 * DAP^{1.7844} * H^{0.3434}$
		Author: Mate *et al.* (2014)	Author: Mugasha *et al.* (2013)
	Pterocarpus angolensis DC.	$\hat{Y} = 0.2201 * DAP^{2.1574}$	$\hat{Y} = 0.1766 * DAP^{1.7844} * H^{0.3434}$
		Author: Mate *et al.* (2014)	Author: Mugasha *et al.* (2013)

	Afzelia quanzensis Welw.	$\hat{Y} = 3.1256 * DAP^{1.5833}$	$\hat{Y} = 0.1766 * DAP^{1.7844} * H^{0.3434}$
		Author: Mate *et al*. (2014)	Author: Mugasha *et al*. (2013)

iv. Estimation

The estimation of mean and their respective uncertainties (standard error, sampling error, and confidence interval) for the variables biomass, carbon and carbon dioxide equivalent (above and below ground) for the two strata (semi-deciduous forest and semi-evergreen forest), were done using the forest inventory data analysis approach proposed by Bechtold & Patterson (2005) chapter 4 of the book "The Enhanced Forest Inventory and Analysis Program-National Sampling Design and Estimation Procedures". Details of this methodology are described in Zambézia inventory report, available at https://www.fnds.gov.mz/mrv/index.php/documentos/relatorios/38-relatorio-de-inventario-florestal-na-zambezia/file.

The approach of Bechtold & Patterson (2005), was used to correct the problem of sample units (clusters) with variable areas. This occurred because the forest type information collected in each cluster at the field level, showed that the clusters transcended the boundaries of the strata (cluster with more than one strata).

For mangrove forests, data are secondary, extracted from existing literature. Stringer *et al*. (2015) made an inventory on this ecosystem in the Zambezi delta in Mozambique; we can easily assume that carbon stocks are comparable to those of mangroves in Zambézia province. They divided mangroves into 5 strata and estimated carbon stocks in above and belowground biomass.

Spatial level: Regional

Value applied:

Semi-deciduous forest (FSD)	144.69
Evergreen forest (FSSV)	123.13
Mangrove forest (FF)	269.01

QA/QC procedures applied

The QA/QC procedures consisted on the following:

- SOPs were developed.
- A training on the SOPs was conducted prior to the field work. This training lasted for 3 weeks, and consisted of training on the usage of all equipment and evaluating the specific skills of each participant, in order to determine the team and brigade leaders. On the start of the 2nd phase of the IFN (2017) an additional 1-week training was conducted, to refresh the participants and train any new members.
- The supervisor of each inventory team conducted a remeasurement of 4 trees per plot which means 16 trees per cluster. This served to ensure that the SOPs were adequately implemented.
- An independent measurement of 10% of the plots. This activity was conducted by technicians of the National Directorate of Forests, who had participated in the Provincial Inventories of Gaza and Cabo Delgado. Diameter below 10%.

	• The adequacy of the allometric models, including root-to-shoot ratios used was confirmed by experts of the Faculty of Agronomy and Forest Engineering (FAEF) and the Department of Biology Sciences (DCB) of the University Eduardo Mondlane (UEM). • The World Bank conducted two regular supervision missions of the National Forest Inventories to confirm the adequate implementation of the SOPs and suggest areas for improvement. The report can be found here. • An independent expert (Jim Alegria, ex-US Forestry Service) was hired in order to evaluate the methodology for the inventory and support in the estimation step. The report can be found here.
Uncertainty associated with this parameter:	<table><tr><th>Forest type</th><th>Uncertainty estimate (confidence interval at 95%)</th></tr><tr><td>FSD</td><td>21.45%</td></tr><tr><td>FSSV</td><td>15.89%</td></tr><tr><td>FF</td><td>8.00%</td></tr></table>
Any comment:	-

Parameter:	$BGB_{before,j}$
Description:	Belowground biomass of forest type *j* before conversion,
Data unit:	tons of dry matter per ha
Source of data or description of the method for developing the data including the spatial level of the data (local, regional, national, international):	For semi-deciduous and evergreen forest, data are from the Zambézia Forest Inventory. It includes data that was collected in Zambézia province during the NFI, in 2017 and 2018. Please refer to parameter $AGB_{before,j}$ for more information. For mangrove forests, data are secondary, extracted from existing literature. Stringer et al. (2015) made an inventory on this ecosystem in the Zambezi delta in Mozambique; we can easily assume that carbon stocks are comparable to those of mangroves in Zambézia province. They divided mangroves into 5 strata and estimated carbon stocks in above and belowground biomass. Spatial level: Regional
Value applied:	<table><tr><td>Semi-deciduous forest (FSD)</td><td>49.98</td></tr><tr><td>Evergreen forest (FSSV)</td><td>42.24</td></tr><tr><td>Mangrove forest (FF)</td><td>85.43</td></tr></table>
QA/QC procedures applied	Please see section QA/QC procedures under parameter $AGB_{before,j}$.
Uncertainty associated with this parameter:	

	Forest type	Uncertainty estimate (confidence interval at 95%)	
	FSD	17.37%	
	FSSV	14.32%	
	FF	10.00%	
Any comment:			

Parameter:	$AGB_{after,i}$
Description:	Aboveground biomass of non-forest type *i* after conversion
Data unit:	tons of dry matter per ha
Source of data or description of the method for developing the data including the spatial level of the data (local, regional, national, international):	For cropland: The values and assumptions of 2006 IPCC GL, Volume 4, Chapter 5 are used. Tier 2 may modify the assumption that carbon stocks immediately following conversion are zero. In this case, it is assumed that conversion leads to annual croplands and in the case the carbon stock in biomass after one year for annual crops provided in TABLE 5.9 is used. For grassland: The values and assumptions of 2006 IPCC GL, Volume 4, Chapter 6 are used. The value of peak-above ground biomass for tropical dry of TABLE 6.4 is assumed. For other lands: No default values exist for these conversions. Spatial level: International
Value applied:	Cropland (C): 10 Grassland (P): 2.3 Other lands (A|O|U): 0.0
QA/QC procedures applied	The adequacy in the use of these default values was confirmed with the experts in GHG Inventory in DINAB.
Uncertainty associated with this parameter:	See table below
Any comment:	Negative lower estimates of uncertainty are set to 0 when running Monte Carlo Simulations.

Value applied:

Cropland (C)	10
Grassland (P)	2.3
Other lands (A|O|U)	0.0

Uncertainty associated with this parameter:

Non-forest type	Uncertainty estimate (confidence interval at 95%)
Cropland (C)	75.00%
Grassland (P)	75.00%
Other lands (A|O|U)	-

Parameter:	$BGB_{after,i}$

<table>
<tr><td>Description:</td><td>Belowground biomass of non-forest type i after conversion</td></tr>
<tr><td>Data unit:</td><td>tons of dry matter per ha</td></tr>
<tr><td>Source of data or description of the method for developing the data including the spatial level of the data (local, regional, national, international):</td><td>For cropland: The values and assumptions of 2006 IPCC GL, Volume 4, Chapter 5 are used. Tier 2 may modify the assumption that carbon stocks immediately following conversion are zero. In this case, it is assumed that conversion leads to annual croplands and in the case the carbon stock in biomass after one year for annual crops provided in TABLE 5.9 is used.

For grassland: The values and assumptions of 2006 IPCC GL, Volume 4, Chapter 6, TABLE 6.1, TABLE 6.4 are used. The value for semi-arid grassland in tropical dry climate zone is used, therefore a root-shoot ratio of 2.8 is applied to the value of aboveground biomass.

For other lands: No default values exist for these conversions.

Spatial level: International</td></tr>
<tr><td>Value applied:</td><td><table><tr><td>Cropland (C)</td><td>0.0</td></tr><tr><td>Grassland (P)</td><td>6.4</td></tr><tr><td>Other lands (A|O|U)</td><td>0.0</td></tr></table></td></tr>
<tr><td>QA/QC procedures applied</td><td>The adequacy in the use of these default values was confirmed with the experts in GHG Inventory in DINAB.</td></tr>
<tr><td>Uncertainty associated with this parameter:</td><td><table><tr><th>Non-forest type</th><th>Uncertainty estimate (confidence interval at 95%)</th></tr><tr><td>Cropland (C)</td><td>-</td></tr><tr><td>Grassland (P)</td><td>75.00%</td></tr><tr><td>Other lands (A|O|U)</td><td>-</td></tr></table></td></tr>
<tr><td>Any comment:</td><td>Negative lower estimates of uncertainty are set to 0 when running Monte Carlo Simulations.</td></tr>
</table>

3.3.2. Calculation of the average annual historical emissions over the Reference Period

The following table shows the average annual historical emissions results obtained per category changes from a forest type to a non-forest type over the Reference Period. The emissions are generated relating the data and parameters described above (Activity data and Emission Factors) and summarized in the Table 2, by applying ***Equation* 3**.

Table 2: Calculation of the average annual historical emissions over the Reference Period

Category changes	Average annual historical activity $data_{j,i}$ (ha/yr)	$AGB_{before,j}$ (tdm/ha)	$BGB_{before,j}$ (tdm/ha)	$AGB_{bafter,i}$ (tdm/ha)	$BGB_{after,i}$ (tdm/ha)	Average annual historical emissions (tCO_2e/yr)
Semi-deciduous forest to cropland	17,505.56	144.69	49.98	10.00	0.00	5,570,976.78
Semi-deciduous forest to grassland	2,435.56	144.69	49.98	2.30	6.44	780,380.99
Semi-deciduous forest to other lands	0.00	144.69	49.98	0.00	0.00	0.00
Evergreen forest to cropland	4,566.67	123.13	42.24	10.00	0.00	1,222,780.11
Evergreen forest to grassland	152.22	123.13	42.24	2.30	6.44	41,089.87
Evergreen forest to other lands	152.22	123.13	42.24	0.00	0.00	43,382.63
Mangrove to cropland	0.00	269.01	85.43	0.00	0.00	0.00
Mangrove to grassland	152.22	269.01	85.43	2.30	6.44	90,687.38
Mangrove to cropland	304.44	269.00	85.40	0.00	0.00	185,960.28
Total						**7,935,258.05**

3.4 Estimated Reference Level

ER Program Reference level

Crediting Period year *t*	**Average annual historical emissions from deforestation over the Reference Period (tCO_{2-e}/yr)**	**If applicable, average annual historical emissions from forest degradation over the Reference Period (tCO_{2-e}/yr)**	**If applicable, average annual historical removals by sinks over the Reference Period (tCO_{2-e}/yr)**	**Adjustment, if applicable (tCO_{2-e}/yr)**	**Reference level (tCO_{2-e}/yr)**
2018	7,935,258.05	-	-	-	7,935,258.05
2019	7,935,258.05	-	-	-	7,935,258.05
2020	7,935,258.05	-	-	-	7,935,258.05
2021	7,935,258.05	-	-	-	7,935,258.05
2022	7,935,258.05	-	-	-	7,935,258.05
2023	7,935,258.05	-	-	-	7,935,258.05
2024	7,935,258.05	-	-	-	7,935,258.05

4 MONITORING AND REPORTING PERIOD

The monitoring and reporting period covers emissions in 2018.

4.1 Measurement, monitoring and reporting approach

Line Diagram

The **Error! Reference source not found.** illustrates the emissions reductions calculation workflow during the Monitoring Period.

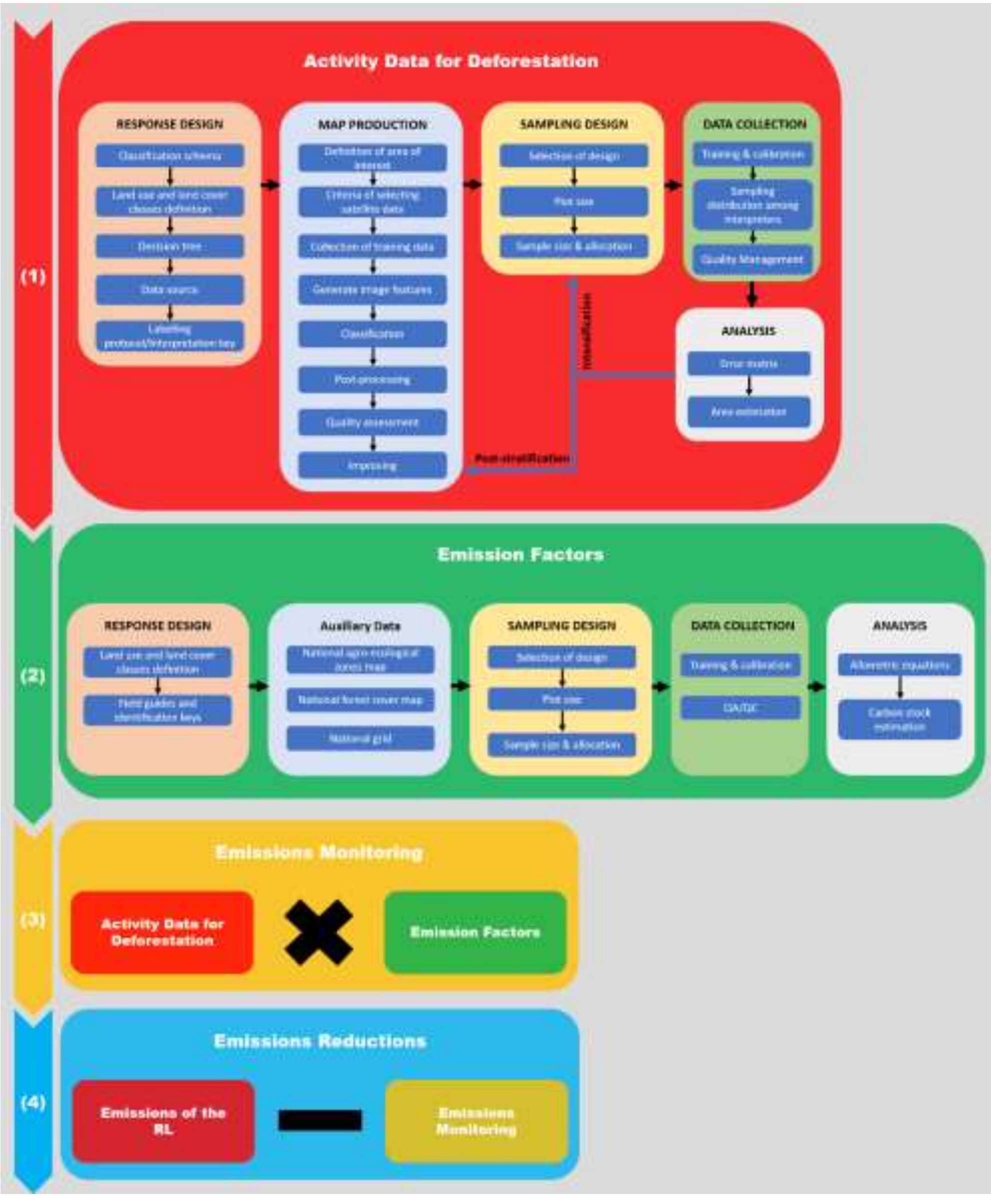

Figure 5: Emissions reductions calculation workflow.

Calculation

$$ER_{ERP,t} = RL_t - GHG_t$$ ***Equation 7***

Where:

ER_{ERP}	=	Emission Reductions under the area outside the scope of ZILMP in year *t*; $tCO_2e*year^{-1}$.
RL_{RP}	=	Gross emissions of the RL from deforestation over the Reference Period; $tCO_2e*year^{-1}$.
GHG_t	=	Monitored gross emissions from deforestation at year *t*; $tCO_2e*year^{-1}$;
T	=	Number of years during the monitoring period; *dimensionless*.

Reference Level $(\mathrm{RL_t})$

Gross emissions of the RL from deforestation over the Reference Period ($\mathrm{RL_{RP}}$) are estimated as the sum of annual change in total biomass carbon stocks ($\Delta \mathrm{C_{B_t}}$) during the reference period.

$$RL_{RP} = \frac{\sum_t^{RP} \Delta C_{B_t}}{RP}$$ ***Equation 8***

Where:

ΔC_{B_t}	=	Annual change in total biomass carbon stocks at year *t; tC*year*$^{-1}$*;*
RP	=	Reference period; *years.*

Following the 2006 IPCC Guidelines, the annual change in total biomass carbon stocks forest land converted to other land-use category *(ΔC_{B_t})* would be estimated through the following equation:

$$\Delta C_{B_t} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$ ***Equation 9***

Where:

ΔC_{B_t}	Annual change of total biomass carbon stocks during the period, in tC per year;
ΔC_G	Annual increase in carbon stocks in biomass due to growth on land converted to another land-use category, in tC per hectare and year;
$\Delta C_{CONVERSION}$	Initial change in carbon stocks in biomass on land converted to other land-use category, in tC per hectare and year; and
ΔC_L	Annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tC per hectare and year.

Following the recommendations set in chapter 2.2.1 of the GFOI Methods Guidance Document for applying IPCC Guidelines and guidance in the context of REDD+[2], the above equation will be simplified and it will be assumed that:

- The annual change in total biomass carbon stocks *(ΔC_B)* is equal to the initial change in carbon stocks *($\Delta C_{CONVERSION}$);*

[2] https://www.reddcompass.org/documents/184/0/MGD2.0_English/c2061b53-79c0-4606-859f-ccf6c8cc6a83

Considering equation 2.16 of the 2006 IPCC GL for estimating *($\Delta C_{CONVERSION}$)* the change of biomass carbon stocks could be expressed with the following equation:

$$\Delta C_{B_t} = \sum_{j,i} \left(B_{Before,j} - B_{After,i}\right) x\ CF\ x \frac{44}{12} \times A(j,i)_{RP} \qquad \textbf{Equation 10}$$

Where:

$A(j,i)_{RP}$ Area converted/transited from forest type *j* to non-forest type *i* during the Reference Period, in *hectares per year*. In this case, three forest land conversions are possible:

- (Semi-)deciduous forest to Non-forest type *i*;
- (Semi-)evergreen forest to Non-forest type *i*; and
- Mangrove forest to Non-forest type *i*.

Five types of non-forest land are considered:

- Cropland (C);
- Grassland (P);
- Wetland (A);
- Settlement (U); and
- Other lands (O).

$B_{Before,j}$ Total biomass of forest type *j* before conversion/transition, in tons of dry matter per ha. This is equal to the sum of aboveground ($AGB_{Before,j}$) and belowground biomass ($BGB_{Before,j}$) and it is defined for each forest type.

$B_{After,i}$ Total biomass of non-forest type *i* after conversion, in *tons dry matter per ha*. This is equal to the sum of aboveground ($AGB_{After,i}$) and belowground biomass ($BGB_{After,i}$) and it is defined for each of the five non-forest IPCC Land Use categories.

CF Carbon fraction of dry matter in tC per ton dry matter. The value used is:

- **0.47** is the default for (sub)tropical forest as per IPCC AFOLU guidelines 2006, Table 4.3.

$44/12$ Conversion of C to CO_2

***Monitored emissions* ($\mathbf{GHG_t}$)**

Annual gross GHG emissions over the monitoring period in the Accounting Area ($\mathrm{GHG_t}$) are estimated as the sum of annual change in total biomass carbon stocks ($\Delta \mathrm{C_{B_t}}$).

$$GHG_t = \frac{\sum_t^T \Delta C_{B_t}}{T} \qquad \textbf{Equation 11}$$

Where:

ΔC_{B_t} = Annual change in total biomass carbon stocks at year *t; tC*year*$^{-1}$

T = Number of years during the monitoring period; *dimensionless*.

Changes in total biomass carbon stocks

Following the 2006 IPCC Guidelines, the annual change in total biomass carbon stocks forest land converted to other land-use category *(ΔC_B)* would be estimated through **Equation 9** above. Making the same assumptions as described above for the RL the change of biomass carbon stocks could be expressed with the following equation:

$$\Delta C_B = \sum_{j,i} \left(B_{Before,j} - B_{After,i}\right) x\ CF\ x \frac{44}{12} \times A(j,i)_{MP}$$ ***Equation 12***

Where:

$A(j,i)_{MP}$ Area converted/transited from forest type *j* to non-forest type *i* during the Monitoring Period, in hectare per year. In this case, three forest land conversions are possible:

- (Semi-)deciduous forest to Non-forest type *i*;
- (Semi-)evergreen forest to Non-forest type *i*; and
- Mangrove forest to Non-forest type *i*.

Five types of non-forest land are considered:

- Cropland (C);
- Grassland (P);
- Wetland (A);
- Settlement (U); and
- Other lands (O).

$B_{Before,j}$ Total biomass of forest type *j* before conversion/transition, in tons of dry matter per ha. This is equal to the sum of aboveground ($AGB_{Before,j}$) and belowground biomass ($BGB_{Before,j}$) and it is defined for each forest type.

$B_{After,i}$ Total biomass of non-forest type *i* after conversion, in *tons dry matter per ha*. This is equal to the sum of aboveground ($AGB_{After,i}$) and belowground biomass ($BGB_{After,i}$) and it is defined for each of the five non-forest IPCC Land Use categories.

CF Carbon fraction of dry matter in tC per ton dry matter. The value used is:

- **0.47** is the default for (sub)tropical forest as per IPCC AFOLU guidelines 2006, Table 4.3.

$44/12$ Conversion of C to CO_2

4.2 Data and parameters

4.2.1 Fixed Data and Parameters

Parameter:	$AGB_{before,j}$
Description:	Aboveground biomass of forest type *j* before conversion,
Data unit:	tons of dry matter per ha
Source of data or description of the method for developing the data including the spatial level of the data (local, regional, national, international):	The data used for the present document are Tier 2 (country specific data or country level estimates or locally derived estimates) and they were sourced from the NFI (for deciduous and evergreen forests) or for Mangrove forests. For semi-deciduous and evergreen forest, data are from the Zambézia Forest Inventory. It includes data that was collected in Zambézia province during the NFI, in 2017 and 2018. The following methods were used from the sampling design to estimation: ***v. Sampling design*** Carbon stocks before conversion for deciduous and evergreen forests were estimated using data from the National Forest Inventory sample units that were located in Zambézia province. The sample units for surveying carbon stocks were allocated using restricted stratified random sampling, using 4 * 4 km systematic grid superimposed on the agro-ecological zoning map, and stratified among the 4 forest types (semi-deciduous forest, semi-evergreen forest, Mopane and Mecrusse forest), of which only semi-deciduous forest and semi-evergreen forest occur in Zambézia province. The total number of sample units was determined using the optimal allocation (assuming a maximum error of 10% for the total volume, and 5% of confidence level). Proportional allocation was used to determine the number of sample units per stratum (Husch, Beers, and Kershaw 2003). For Zambézia province, 128 clusters (512 plots) were distributed between the two forest types. The cluster was used as a sampling unit, and each cluster has 4 plots of 0.1 ha (20 * 50 m), where each plot was divided into 4 sub-plots of 0.025 ha (10 * 25 m) (Figure 4). ***vi. Data collection*** The plots were used for data collection of adult trees (dbh≥10cm), and the subplots "A" were used for data collection of established regeneration trees (10cm> dbh≥ 5 cm), which were included in the calculation of the carbon stocks. Data collected in the plots and subplots included tree information (dbh, scientific name, total and commercial height, stem quality), soil, forest type (this information was used to validate the information from agro-ecological zoning map), and other important information. Tree data were used to estimate above ground biomass (AGB) and below ground biomass (BGB). The NFI did not cover Mangrove forests, so, data from the literature was used. For other strata, data from literature were also used. Details of data collection can be find at https://www.fnds.gov.mz/mrv/index.php/documentos/guioes/35-directrizes-do-inventario-florestal-nacional/file . ***vii. Prediction at plot level***

	Above ground biomass (AGB) and below ground biomass (BGB) were estimated using a series of allometric equations adjusted for ecosystems or tree species similar to those in the Zambézia province (Table 1), and this equation was applied at tree level. The use of the equations meant, applying allometric equations of the specific species (*Millettia stuhlmannii* taub., *Pterocarpus angolensis* DC., *Afzelia quanzensis* Welw.) in all trees of these species to estimate AGB, regardless of forest types. The allometric equation of the semi-deciduous forest was applied for all trees of this forest type (except the above species), as well as in all trees of the species *Brachystegia spiciformis* Benth., and *Julbernardia globiflora* (Benth.) Troupin to estimate AGB and BGB, because they were the main species used to adjust this equation in this forest type. The equations of the semi-evergreen forest were applied in all remaining trees of this forest type to estimate AGB; and apply the semi-deciduous forest equation in all trees to estimate the BGB in this forest type (including species mentioned above in other forest type), and apply factor 0.28 (shoot ratio) to estimate the BGB of the semi-evergreen forest. ***viii. Estimation*** The estimation of mean and their respective uncertainties (standard error, sampling error, and confidence interval) for the variables biomass, carbon and carbon dioxide equivalent (above and below ground) for the two strata (semi-deciduous forest and semi-evergreen forest), were done using the forest inventory data analysis approach proposed by Bechtold & Patterson (2005) chapter 4 of the book “The Enhanced Forest Inventory and Analysis Program-National Sampling Design and Estimation Procedures”. Details of this methodology are described in Zambézia inventory report, available at https://www.fnds.gov.mz/mrv/index.php/documentos/relatorios/38-relatorio-de-inventario-florestal-na-zambezia/file. The approach of Bechtold & Patterson (2005), was used to correct the problem of sample units (clusters) with variable areas. This occurred because the forest type information collected in each cluster at the field level, showed that the clusters transcended the boundaries of the strata (cluster with more than one strata). For mangrove forests, data are secondary, extracted from existing literature. Stringer *et al*. (2015)[3] made an inventory on this ecosystem in the Zambezi delta in Mozambique; we can easily assume that carbon stocks are comparable to those of mangroves in Zambézia province. They divided mangroves into 5 strata and estimated carbon stocks in above and belowground biomass. Spatial level: Regional
Value applied:	Semi-deciduous forest (FSD): 144.69 Evergreen forest (FSSV): 123.13 Mangrove forest (FF): 269.01
QA/QC procedures applied	The QA/QC procedures consisted on the following: • SOPs were developed as described in *Section* ***Error! Reference source not found.*** - ***Error! Reference source not found.***.

[3] Stringer, C. E.; Trettin, C. C.; Zarnoch, S. J. and Tang, W. 2015. Carbon stocks of mangroves within the Zambezi River Delta, Mozambique. Forest Ecology Management 354:139–148.

	• A training on the SOPs was conducted prior to the field work. This training lasted for 3 weeks, and consisted of training on the usage of all equipment and evaluating the specific skills of each participant, in order to determine the team and brigade leaders. On the start of the 2nd phase of the IFN (2017) an additional 1-week training was conducted, to refresh the participants and train any new members. • The supervisor of each inventory team conducted a remeasurement of 4 trees per plot which means 16 trees per cluster. This served to ensure that the SOPs were adequately implemented. • An independent measurement of 10% of the plots. This activity was conducted by technicians of the National Directorate of Forests, who had participated in the Provincial Inventories of Gaza and Cabo Delgado. Diameter below 10%. • The adequacy of the allometric models, including root-to-shoot ratios used was confirmed by experts of the Faculty of Agronomy and Forest Engineering (FAEF) and the Department of Biology Sciences (DCB) of the University Eduardo Mondlane (UEM). • The World Bank conducted two regular supervision missions of the National Forest Inventories to confirm the adequate implementation of the SOPs and suggest areas for improvement. The report can be found here. • An independent expert (Jim Alegria, ex-US Forestry Service) was hired in order to evaluate the methodology for the inventory and support in the estimation step. The report can be found here.
Uncertainty associated with this parameter:	(see table below)
Any comment:	-

Forest type	Uncertainty estimate (confidence interval at 95%)
FSD	21.45%
FSSV	15.89%
FF	8.00%

Parameter:	$BGB_{before,j}$
Description:	Belowground biomass of forest type *j* before conversion,
Data unit:	tons of dry matter per ha
Source of data or description of the method for developing the data including the spatial level of the data (local, regional, national, international):	For semi-deciduous and evergreen forest, data are from the Zambézia Forest Inventory. It includes data that was collected in Zambézia province during the NFI, in 2017 and 2018. Please refer to parameter $AGB_{before,j}$ for more information. For mangrove forests, data are secondary, extracted from existing literature. Stringer et al. (2015) made an inventory on this ecosystem in the Zambezi delta in Mozambique; we can easily assume that carbon stocks are comparable to those of mangroves in Zambézia province. They divided mangroves into 5 strata and estimated carbon stocks in above and belowground biomass. Spatial level: Regional
Value applied:	(see table below)

Semi-deciduous forest (FSD)	49.98

	<table><tr><td>Evergreen forest (FSSV)</td><td>42.24</td></tr><tr><td>Mangrove forest (FF)</td><td>85.43</td></tr></table>
QA/QC procedures applied	Please see section QA/QC procedures under parameter $AGB_{before,j}$.
Uncertainty associated with this parameter:	<table><tr><th>Forest type</th><th>Uncertainty estimate (confidence interval at 95%)</th></tr><tr><td>FSD</td><td>17.37%</td></tr><tr><td>FSSV</td><td>14.32%</td></tr><tr><td>FF</td><td>10.00%</td></tr></table>
Any comment:	-

Parameter:	$AGB_{after,i}$
Description:	Aboveground biomass of non-forest type *i* after conversion
Data unit:	tons of dry matter per ha
Source of data or description of the method for developing the data including the spatial level of the data (local, regional, national, international):	For cropland: The values and assumptions of 2006 IPCC GL, Volume 4, Chapter 5 are used. Tier 2 may modify the assumption that carbon stocks immediately following conversion are zero. In this case, it is assumed that conversion leads to annual croplands and in the case the carbon stock in biomass after one year for annual crops provided in TABLE 5.9 is used. For grassland: The values and assumptions of 2006 IPCC GL, Volume 4, Chapter 6 are used. The value of peak-above ground biomass for tropical dry of TABLE 6.4 is assumed. For other lands: No default values exist for these conversions. Spatial level: International
Value applied:	<table><tr><td>Cropland (C)</td><td>10</td></tr><tr><td>Grassland (P)</td><td>2.3</td></tr><tr><td>Other lands (A|O|U)</td><td>0.0</td></tr></table>
QA/QC procedures applied	The adequacy in the use of these default values was confirmed with the experts in GHG Inventory in DINAB.
Uncertainty associated with this parameter:	<table><tr><th>Non-forest type</th><th>Uncertainty estimate (confidence interval at 95%)</th></tr><tr><td>Cropland (C)</td><td>75.00%</td></tr><tr><td>Grassland (P)</td><td>75.00%</td></tr><tr><td>Other lands (A|O|U)</td><td>-</td></tr></table>

Any comment:	-

Parameter:	$BGB_{after,i}$
Description:	Belowground biomass of non-forest type *i* after conversion
Data unit:	tons of dry matter per ha
Source of data or description of the method for developing the data including the spatial level of the data (local, regional, national, international):	For cropland: The values and assumptions of 2006 IPCC GL, Volume 4, Chapter 5 are used. Tier 2 may modify the assumption that carbon stocks immediately following conversion are zero. In this case, it is assumed that conversion leads to annual croplands and in the case the carbon stock in biomass after one year for annual crops provided in TABLE 5.9 is used. For grassland: The values and assumptions of 2006 IPCC GL, Volume 4, Chapter 6, TABLE 6.1, TABLE 6.4 are used. The value for semi-arid grassland in tropical dry climate zone is used, therefore a root-shoot ratio of 2.8 is applied to the value of aboveground biomass. For other lands: No default values exist for these conversions. Spatial level: International
Value applied:	Cropland (C): 0.0 Grassland (P): 6.4 Other lands (A|O|U): 0.0
QA/QC procedures applied	The adequacy in the use of these default values was confirmed with the experts in GHG Inventory in DINAB.
Uncertainty associated with this parameter:	(see table below)
Any comment:	-

Non-forest type	Uncertainty estimate (confidence interval at 95%)
Cropland (C)	-
Grassland (P)	75.00%
Other lands (A|O|U)	-

4.2.2 Monitored Data and Parameters

Parameter:	$A(j,i)_{MP}$
Description:	Area converted from forest type *j* to non-forest type *i* during the Monitoring Period.
Data unit:	hectare per year.

Value monitored during this Monitoring / Reporting Period:

Semi-deciduous forest to cropland	5,073.93
Semi-deciduous forest to grassland	0.0
Semi-deciduous forest to other lands	0.0
Evergreen forest to cropland	452.92
Evergreen forest to grassland	0.0
Evergreen forest to other lands	0.0
Mangrove forest to cropland	0.0
Mangrove forest to grassland	0.0
Mangrove forest to other lands	0.0

Source of data and description of measurement/calculation methods and procedures applied:

i. Source

Activity data used for the monitoring period are obtained from a combination of an annual wall-to-wall deforestation map with sampling to generate deforested area estimates through a stratified estimator.

ii. Variable of interest

The variable of interest are all the transitions specified above. It is important to note that the variables of interest are not aligned to the strata as this is not required. Strata is linked to the likelihood of presence of deforestation events, whereas the variable of interest is linked to the possible transitions of deforestation per forest type and post-deforestation type.

ii. Annual deforestation map

The workflow used to produce annual deforestation map for the area outside the scope of ZILMP follows the steps below:

1. Produce two Sentinel-2 satellite imagery composites for the monitoring area, containing all images of wet season (i.e. November - May). The first composite comprises the period between November 2017 to May 2018 denoted as the reference period and the second composite comprises the period from November 2018 to May 2019, referred as actual period. The reason behind the selection of November- May as a reference and actual period of monitoring resides on the fact that it is the wet season, where the NDVI stability is very high in relation to the dry season, which starts in June to October, when most trees lose their foliage and makes it difficult the analysis of deforestation.
2. Generate image features from reference period and actual period from the composites generated in previous step, to identify changes in forest cover. The image features have different vegetation indexes, namely, NDVI, EVI, SAVI, NBR, NDWI with respective sub-products such as NDVI 90th percentile, Normalized NDVI, and variation on NDVI.
3. Generate training data on classes of deforestation, stable forest and stable non-forest by visual interpretation of composites from the reference and actual periods, and NDVI change detection image. The NDVI change detection image is a result of the difference of NDVI from the composites of reference and actual

periods. The calculated NDVI change detection image helps the interpreter to locate where the changes of forest cover are occurring.

4. Produce a categorical deforestation map from training data and image features through a process of classification using Random Forest classifier. The Categorical deforestation map includes non-forest stable and stable forest classes. Because errors of omission of deforestation have a very large impact on the final estimates, it is important to reduce these errors as much as possible.
5. To improve the efficacy of the sampling the deforestation class on the map is reclassified as:
   a) High probability deforestation (cluster of more than 10 pixels of deforestation, corresponding to at least 40% of one hectare);
   b) Low probability of deforestation (cluster of less than 10 pixels and greater than 6 pixels, corresponding at least 24%- to 40% of one hectare) and;
   c) Non-forest (cluster of less than 6 pixels, corresponding to less than 20% of a hectare).
6. To reduce the risk of omission errors, a Buffer of 40 meters is added around the high probability of deforestation class. The result is a deforestation map with five classes: High probability of deforestation; buffer; low probability of deforestation; stable forest and stable non-forest.

v. Sampling design

Sampling method

Monitoring of activity data for annual reporting is conducted using a stratified estimator, where deforestation map (which includes classes of forest and non-forest) is used for stratification and reference-sampling units are used for estimate activity data and associated confidence intervals.

Sample size determination

The sample size *n* was determined from the equation:

$$n = \frac{(\sum W_i S_i)^2}{[S(\hat{O})]^2 + (\frac{1}{N})\sum W_i S_i} \approx \left(\frac{\sum W_i S_i}{S(\hat{O})}\right)^2 \qquad \textbf{Equation 13}$$

Where:

N	Number of units in the ROI
$S(\hat{O})$	Standard error of the estimated overall accuracy that we would like to achieve
W_i	Mapped proportion of area of class *i*; and
S_i	Standard deviation of stratum *i*.

The standard deviation of stratum *i* is given by the formula:

$$S_i = \sqrt{U_i(1 - U_i)}$$ ***Equation 14***

Where:

U_i	Proportion of area of deforestation in stratum *i.*

In order to obtain approximate values of proportion of deforestation in each stratum (U_i), a pilot sampling is conducted. This pilot consists of 100 sample units per stratum.

Sample units per stratum

After the pilot sampling, sample units may need to be added to each stratum, in order to reach the desired relative error. It was decided to use the Optimum (Neyman) allocation, where the stratum standard deviation $S_h = \sqrt{U_h \cdot (1 - U_h)}$ increases the number of plots (ensuring larger numbers of plots in rare classes or strata) and sampling unit costs are constant:

$$n_h = n \frac{w_h \cdot S_h}{\sum_{h=1}^{H} w_h \cdot S_h}$$ ***Equation 15***

The technical team, with support from a renowned international expert (Steve Stehman) decided that there should be a minimum of 300 sample units in the stable classes. The reason behind this minimum is that if no deforestation events are found in the 100 sample units of each stable stratum, then *pi* will be 0, and we would require no further sampling of these strata. This would mean that our sample size for the stable strata would be much smaller than for the change strata.

Post-stratification of stable classes

After the initial stratification be conducted and the reference data collected, visual inspection of the map showed that there were errors of omission, even though the reference data did not include any. The original deforestation map for Zambézia 2017-2018 was produced with a rudimentary version of our map production workflow, which was improved since then. The technical team, with the support from a renowned international expert (Steve Stehman) decided to produce a post-stratification of the stable classes using the new map production workflow. This stratification was composed of the same classes of change: high probability of deforestation, buffer and low probability of deforestation. However, these were merged prior to the collection of reference data, in order to reduce the effort in collection of new reference data. The final number of reference points is presented in **Error! Reference source not found.**.

Table 3: Number of reference sampling units per map stratum. "New deforestation" stratum represents the post-stratification conducted on the stable classes, after it was found that the original map was omitting deforestation.

Stratum	Number of sample units
High probability of deforestation	125
40 m Buffer	124
Low probability of deforestation	125

Forest	300
Non-forest	300
New deforestation	100
Total	1074

v. Response design

Sampling unit and spatial support

The sampling unit is a 20 m pixel of the stratification map that was produced. The spatial support used is a 100m x 100m plot (1ha). Each Spatial sampling unit contains an internal grid of 5 x 5 points (20m x 20m grid) to aid in the labelling attribution (Figure 1).

Source of reference data

Each sampling unit was evaluated using Collect Earth (http://www.openforis.org/). This tool enables access to high-resolution images in Google Earth, Bing Maps and Planet Labs, as well as a medium resolution image repository available through Google Earth Engine Explorer and Code Editor (Landsat and Sentinel-2). The tool enables to display digital forms designed to collect the Land-Use Land Cover Change and Forestry (LULCCF) information on the sampling points (Figure 2). The Earth Engine Code Editor facilitates the interpretation of the vegetation type and the determination of LULC changes, by displaying the historical MOD13Q1 (NDVI 16-day Global Modis 250 m) graphic as well as monthly mosaics of Sentinel-2 images. The main source of data to identify changes in land cover, is Sentinel-2 monthly composites. However, Planet data is also used in cases of doubt or excessive cloud cover with Sentinel-2.

Reference labelling protocol

The activity data was generated considering the national land use and land cover classification system, which reflects the six broad IPCC Land Use categories.

A set of hierarchical rules were established and used to determine the LULCCF category based on a certain percentage and taking into account the national forest definition as well (Figure 3). A single land use class is easier to classify, but it becomes challenging when there is a combination of two or more land use classes within the area of interest. Thus, this is where the hierarchical rules are important to determine the land use. Any sampling unit that has 30% of tree canopy cover is considered a forest, according to the national forest definition, even if it has more than 20% of settlements, crops or other land use, the forest has priority.

In the case the sampling unit was classified as forest land and different forest types were present in the sampling unit, a majority rule was used in this case, i.e. the largest forest class is the winner.

vi. Analysis

Applying the methodology described in Olofsson *et al*. (2014)[4] and the GFOI MGD the estimations of the areas corresponding to land-use and land-cover change categories, more specifically the activity data for deforestation, in the framework of this stratified random sampling approach (based on the visual assessment of the 1 ha plots) was based on assessments of area proportions. A sample error matrix is constructed where

Map data	Reference data					Total	User's accuracy ($\hat{U}_i$)
	Deforestation			Stable forest	Stable non-forest		
	High probability of deforestation	40 m Buffer	Low probability of deforestation				
High probability of deforestation	$\hat{p}_{11}$	$\hat{p}_{12}$	$\hat{p}_{13}$	$\hat{p}_{14}$	$\hat{p}_{15}$	$\hat{p}_{1\cdot}$	$\hat{p}_{11}/\hat{p}_{1\cdot}$
40 m Buffer	$\hat{p}_{21}$	$\hat{p}_{22}$	$\hat{p}_{23}$	$\hat{p}_{24}$	$\hat{p}_{25}$	$\hat{p}_{2\cdot}$	$\hat{p}_{22}/\hat{p}_{2\cdot}$
Low probability of deforestation	$\hat{p}_{31}$	$\hat{p}_{32}$	$\hat{p}_{33}$	$\hat{p}_{34}$	$\hat{p}_{35}$	$\hat{p}_{3\cdot}$	$\hat{p}_{33}/\hat{p}_{3\cdot}$
Stable forest	$\hat{p}_{41}$	$\hat{p}_{42}$	$\hat{p}_{43}$	$\hat{p}_{44}$	$\hat{p}_{45}$	$\hat{p}_{4\cdot}$	$\hat{p}_{44}/\hat{p}_{4\cdot}$
Stable non-forest	$\hat{p}_{51}$	$\hat{p}_{52}$	$\hat{p}_{53}$	$\hat{p}_{54}$	$\hat{p}_{55}$	$\hat{p}_{5\cdot}$	$\hat{p}_{55}/\hat{p}_{5\cdot}$
Total	$\hat{p}_{\cdot 1}$	$\hat{p}_{\cdot 2}$	$\hat{p}_{\cdot 3}$	$\hat{p}_{\cdot 4}$	$\hat{p}_{\cdot 5}$	1	
Producer's accuracy (P_i)	$\hat{p}_{11}/\hat{p}_{\cdot 1}$	$\hat{p}_{22}/\hat{p}_{\cdot 2}$	$\hat{p}_{33}/\hat{p}_{\cdot 3}$	$\hat{p}_{44}/\hat{p}_{\cdot 4}$	$\hat{p}_{55}/\hat{p}_{\cdot 5}$		Overall accuracy ($\hat{O}$) $= \hat{p}_{11} + \hat{p}_{22} + \hat{p}_{33} + \hat{p}_{44} + \hat{p}_{55}$

the map classes (h=1, 2,…,q) are represented by rows and the reference data (k=1, 2,…,q) by columns as shown in Table 4.

Table 4: Error matrix of area proportions

The mean estimator for the area of each class can be directly obtained from the error matrix. Unbiased stratified estimators are provided using reference class area proportions ($\hat{p}_{\cdot k}$):

$$\hat{p}_{\cdot k} = \sum_{h=1}^{H} w_h \cdot \frac{n_{hk}}{n_{h\cdot}} = \sum_{h=1}^{H} \hat{p}_{hk} \qquad \textbf{Equation 16}$$

Where:

$\hat{p}_{\cdot k}$ Area proportions of reference data class k. These proportions of reference d for deforestation classes as a whole are collapsed in three possible types of conversions/transitions from forest type j to non-forest type i, namely:

- Broadleaved (Semi-) deciduous to Non-forest type i;
- Broadleaved (Semi-) evergreen to Non-forest type i; and

[4] Olofsson, P., Foody, G.M., Herold, M., Stehman, S.V., Woodcock, C.E., & Wulder, M.A. 2014. Good practices for estimating area and assessing accuracy of land change. Remote Sensing of Environment. 148:42-57.

	• Mangrove to Non-forest type *i*. Five types of non-forest land are considered: • Cropland (C); • Grassland (P); • Wetland (A); • Settlement (U); and • Other lands (O). w_h Proportion of area mapped as class *h*; n_{hk} Sample count at cell (*h,k*); $n_{h.}$ Sum of sample counts across row *h*; and $\hat{p}_{hk}$ Proportion of area in cell (*h,k*). Once the estimated reference class area proportions ($\hat{p}_{\cdot k}$) are obtained, the mean total area per class is calculated by multiplying them with the total reporting area ***a***: $$\hat{A}_j = \hat{p}_{\cdot k} \cdot a$$ ***Equation 17*** The estimated standard error for the reference class area proportions was given by: $$S(\hat{p}_{\cdot j}) = \sqrt{\sum_{h=1}^{H} w_h^2 \cdot \frac{\hat{p}_{hj} \cdot (1 - \hat{p}_{hj})}{n_{h\cdot} - 1}}$$ ***Equation 18*** where the term inside the root is the variance of the reference class area proportion. Translated to actual area, $$S(\hat{A}_j) = S(\hat{p}_{\cdot j}) \cdot a$$ ***Equation 19*** Given the confidence level (i.e., 95%, expressed as a fraction, that is, 0.95), the significance level is $\alpha = 1 - confidence\ level$, one must use Student's t given α and the degrees of freedom, $df = n_{h\cdot} - 1$. For large samples, $df \rightarrow 1.96$. Then the confidence interval of the estimated area per class was given by: $$CI(\hat{A}_j) = t_{\alpha,df} \cdot S(\hat{p}_{\cdot j})$$ ***Equation 20*** The uncertainty, usually represented as a percentage, then becomes: $$U(\hat{A}_j) = \frac{CI(\hat{A}_j)}{\hat{A}_j} \cdot 100$$ ***Equation 21***
QA/QC procedures applied:	The QA/QC procedures consisted on the following: • SOPs were developed as described in *Section* ***Error! Reference source not found.*** - ***Error! Reference source not found.*** and training; and • Interpretation is done by highly qualified professionals which are specialized in land cover interpretation with satellite imagery. They were trained and a robust control system is in place to ensure that they are correctly calibrated throughout the data collection process. • All reference data interpreted as deforestation, and an additional 20% of the remaining reference data. The quality control is carried out by two

<table>
<tr>
<td></td>
<td>independent supervisors, who after the independent evaluation compare the two evaluations and consensually compile a single comment for each sample. The parameters to be taken into account in the evaluation for identifying errors are: a) the percentage of coverage for each element within the plot; b) the current land cover/land use class (levels 1 and 2); c) the land cover/land use change class; d) the former land cover/land use class (levels 1 and 2); and e) the date of occurrence of land cover/land use change, or evidence date of remaining land cover/land use. If there are gross errors related to the parameters b), c) and d) in at least 20% of samples from the 20% mentioned initially, the respective interpreter should review all samples from the batch, otherwise the interpreter reviews only the samples evaluated by the supervisors, that present gross errors. On the other hand, in relation to all samples interpreted as deforestation, the interpreter reviews only the samples that present gross errors according to the evaluation from the supervisors. The process is cyclical until the interpreter achieves values less than 20% of gross errors in the batch.
• The sampling design and estimation was reviewed by an international renowned expert (Steve Stehman), a statistics professor of State University of New York.</td>
</tr>
<tr>
<td>Uncertainty for this parameter:</td>
<td>
<table>
<tr><th>Category change</th><th>Uncertainty estimate (confidence interval at 95%)</th></tr>
<tr><td>FSD>C</td><td>16.75%</td></tr>
<tr><td>FSSV>C</td><td>73.96%</td></tr>
</table>
</td>
</tr>
<tr>
<td>Any comment:</td>
<td>-</td>
</tr>
</table>

5 QUANTIFICATION OF EMISSION REDUCTIONS

5.1 Reference level for the Monitoring / Reporting Period covered in this report

Year of Monitoring/Reporting period *t*	Average annual historical emissions from deforestation over the Reference Period (tCO_{2-e}/yr)	If applicable, average annual historical emissions from forest degradation over the Reference Period (tCO_{2-e}/yr)	If applicable, average annual historical removals by sinks over the Reference Period (tCO_{2-e}/yr)	Adjustment, if applicable (tCO_{2-e}/yr)	Reference level (tCO_{2-e}/yr)
2018	7,935,258.05	-	-	-	7,935,258.05
Total	**7,935,258.05**	**-**	**-**	**-**	**7,935,258.05**

5.2 Estimation of emissions by sources and removals by sinks included

The following table shows the emissions results obtained per category changes from a forest type to a non-forest type during the Monitoring Period. The emissions are generated relating the data and parameters described in Section 4 and summarized in the Table 5, by applying **Equation 12**.

Table 5: Calculation of the emissions during the Monitoring Period

Category changes	$A_{(j,i)MP}$ (ha)	$AGB_{before,j}$ (tdm/ha)	$BGB_{before,j}$ (tdm/ha)	$AGB_{after,i}$ (tdm/ha)	$BGB_{after,i}$ (tdm/ha)	Emissions (tCO_2e)
Semi-deciduous forest to cropland	5,073.93	144.69	49.98	10.00	0.00	1,614,729.56
Semi-deciduous forest to grassland	0.00	144.69	49.98	2.30	6.40	0.00
Semi-deciduous forest to other lands	0.00	144.69	49.98	0.00	0.00	0.00
Evergreen forest to cropland	452.92	123.13	42.24	10.00	0.00	121,275.99
Evergreen forest to grassland	0.00	123.13	42.24	2.30	6.40	0.00
Evergreen forest to other lands	0.00	123.13	42.24	0.00	0.00	0.00
Mangrove to cropland	0.00	269.01	85.43	10.00	0.00	0.00
Mangrove to grassland	0.00	269.01	85.43	2.30	6.40	0.00

Mangrove to other lands	0.00	269.01	85.43	0.00	0.00	0.00
Total						**1,736,005.55**

Year of Monitoring/Reporting Period	**Emissions from deforestation (tCO_{2-e}/yr)**	**If applicable, emissions from forest degradation (tCO_{2-e}/yr)***	**If applicable, removals by sinks (tCO_{2-e}/yr)**	**Net emissions and removals (tCO_{2-e}/yr)**
2018	1,736,005.55	-	-	1,736,005.55
Total	1,736,005.55	-	-	**1,736,005.55**

5.3 Calculation of emission reductions

Total Reference Level emissions during the Monitoring Period (tCO_2-e)	7,935,258.05
Net emissions and removals under the ER Program during the Monitoring Period (tCO_2-e)	1,736,005.55
Emission Reductions during the Monitoring Period (tCO_2-e)	6,199,252.50
Length of the Reporting period / Length of the Monitoring Period (# days/# days)	230/365
Emission Reductions during the Reporting Period (tCO_2-e)	**3,906,378.29**

6 UNCERTAINTY OF THE ESTIMATE OF EMISSION REDUCTIONS

Uncertainties were propagated using the Tier 1 method of the 2006 IPCC GL, i.e. propagation of uncertainties. The following equations were used for addition or multiplication.

For addition or subtraction:

$$U_{total} = \frac{\sqrt{(U_1.x_1)^2 + (U_2.x_2)^2 + \cdots + (U_n.x_n)^2}}{|x_1 + x_2 + \cdots + x_n|}$$ ***Equation 22***

Where:

U_i	Percentage uncertainty associated with each of the parameters
X_i	The value of the parameter
U_{total}	The percentage uncertainty in the sum of parameters

For multiplication:

$$U_{total} = \sqrt{{U_1}^2 + {U_2}^2 + \cdots + {U_n}^2}$$ ***Equation 23***

Where:

U_i	Percentage uncertainty associated with each of the parameters
X_i	The value of the parameter
U_{total}	The percentage uncertainty in the multiplication of parameters

Uncertainty of Reference Level emissions during the Monitoring Period (%)	19.88
Uncertainty of net emissions and removals under the ER Program during the Monitoring Period (%)	23.41
Uncertainty of Emission Reductions during the Reporting Period (%)	**26.28**