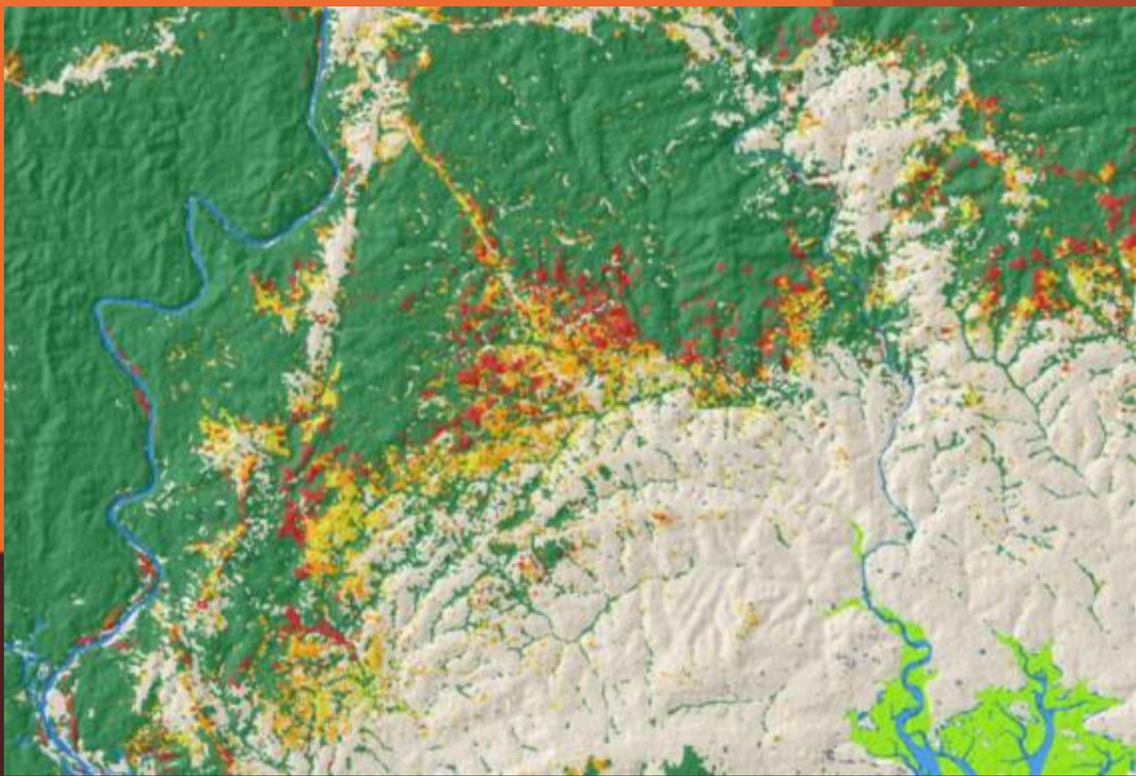
Background study for the preparation of the Zambézia Integrated Landscapes Management Program



Final Report
June 2016

Zambézia Integrated Landscapes Management Program

Background study

Analysis of dynamics and causes of deforestation and forest degradation and related emissions
Actions and institutional arrangements to reduce deforestation

Final report in date of the 14th of June 2016

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Executive Summary

Concerned about growing deforestation in the Zambézia Province and building on a pilot REDD+ project around the Gilé National Reserve**, the Government of Mozambique (GoM) selected 7 districts**[1] **in this province to implement a jurisdictional REDD+ program: the *Zambézia Integrated Landscapes Management Program* (ZILMP)**.

Those seven districts have suffered significant deforestation over the last 25 years, with 14% of the 1990 forest cover being already lost – i.e. 300,000 hectares (ha). Deforestation has been more intense in the north of the area: the forest-dominated landscapes of Alto-Molocué and Ilé districts have turned into ones now dominated by small-scale agriculture. Those two districts have lost around one-fourth of their forest cover. **Worse, in the ZILMP area, deforestation has increased** from 0.55% per year between 2000 and 2005 to 0.86% per year between 2010 and 2013. Today, deforestation is spreading along the formerly well-preserved southern area of the province; even the Gilé National Reserve (GNR) is now facing increasing deforestation rates in its buffer zone.

The ZILMP, which aims at reducing deforestation by 30% to 40%, **will require drastic changes in agricultural and bio-energy production patterns, as well as in terms of governance** - the forest sector being doomed by corruption and illegality. To this end, the GoM is seeking the support of the *Carbon Fund of the Forest Carbon Partnership Facility (FCPF CF)*. **This study gathers data** (through surveys, field inventories, satellite images analysis, bibliography, etc.) **to help design a REDD+ program that meets the requirements of the FCPF CF methodological framework** and that could be accepted by the FCPF CF board.

In this framework, **the forest cover to be considered is 1.98 millions ha**, representing 51% of the 3.87 millions ha of the ZILMP area. The mean historical deforestation for the 2005 – 2013 reference period is **14,798 ha ± 293 ha** (90% confidence interval). The emission factor for the Miombo forest is **250.8 tCO_2eq/ha** and the baseline emissions from deforestation are **3.3 MtCO_2eq/year**. Forest degradation will also have to be accounted for, since it represents more than 10% of deforestation emissions. With conservative hypothesis on degradation, the total baseline emissions would be **3.9 MtCO_2eq/year**. On the contrary, mangroves will not have to be taken into account and neither will soils.

Deforestation is almost exclusively driven by small-scale agriculture for maize and cassava - which represent 56% to 75% of agricultural lands. Smallholders open new plots for fertility purposes and with a view to limiting workload for weeding. Agriculture intensification is not

[1] Gilé, Pebane, Ilé, Alto-Molocué, Mulevala, Mocubela and Maganja da Costa

constrained by land but by work during the peak season. This maize – cassava agriculture is poorly linked to market and consists mainly of subsistence agriculture. Sesame and cashew are the main cash crops of the area but do not lead to deforestation, and neither do others cash crops like tobacco or cotton. Ultimately, **transforming agricultural practices for maize and cassava should be the core of this REDD+ program** - bearing in mind that such a transformation will be difficult. Since mineral fertilization and the introduction of livestock cannot be considered as options**, alternative practices based on agro-ecology should be promoted**. In order for them to be adopted, those agro-ecology alternatives should adapt to smallholders' strategies and comprise intense technical support that will be directly provided to smallholders by a large extension team. Finally, **this agro-ecology package will be completed by activities aiming at increasing revenue from cash crops to ease risk-taking and investment by smallholders**.

As agriculture is not constrained by land access, land planning does not appear to us as a priority activity to address deforestation. In relation to the ER-PIN, we propose an important budget shift from land planning towards agro-ecology extension.

Degradation from charcoal production could be lowered through **increased efficiency of charcoal production** and through **a better management of wood resources, benefiting from the great regeneration potential of the Miombo forest**. It would also imply to account for carbon sequestration with assisted natural regeneration.

According to us, **degradation from illegal logging will be difficult to address - even with the recently endorsed new policy package -** without a major shift of behavior of all stakeholders within the forest sector. This requires **a high-political buy-in of this program and a provincial governor level management.** We think that **a dedicated team responsible for transparency and juridical support** would be useful in achieving this transformation.

Finally, since agriculture should be at the very heart of this program, **the implication of the Ministry of Agriculture will be fundamental** for its good implementation.

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Acronyms

ACi	African Cashew initiative
AFD	Agence Française de Développement – French Development Agency
AGB	Aboveground Biomass
ANR	Assisted Natural Regeneration
BGB	Belowground Biomass
CDM	Clean Development Mechanism
CEPAGRI	Centro de Promoção da Agricultura
DEM	Digital Elevation Model
DB	Database
DPASA	Direção Provincial da Agricultura e Segurança Alimentar
DPTADER	Direção Provincial Terras, Ambiente e Desenvolvimento Rural
ER	Emissions Reduction
ER-PIN	Emission Reduction Project Idea Note
ER-PD	Emission Reduction Program Document
FCPF	Forest Carbon Partnership Facility
FCPF CF	Carbon Fund of the Forest Carbon Partnership Facility
FCPF MF	Methodological Framework of the Forest Carbon Partnership Facility Carbon Fund (FCPF 2013)
FFEM	Fond Français pour l'Environnement Mondial – French Global Environment Facility
FOM	Figure of Merit
GIS	Geographical Information System
GLS	Global Land Survey
GNR	Gilé National Reserve
GoM	Government of Mozambique
IGF	International Foundation for Wildlife Management
IIED	International Institute for Environment and Development
IPCC	International Panel on Climate Change
JNR	Jurisdictional and Nested REDD+
ltHWP	Long Term Harvested Wood Products
LULCC	Land Uses and Land Cover Change
MMU	Minimum Mapping Unit
OOB	Out Of Bag error
PDUT	Plano Distrital de Uso da Terra

PES	Payment for Ecosystem Services
PPI	Progress out Poverty Index
RCN	Raw Cashew Nut
REDD+	Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
REL	Reference Emissions Level
RGB	Red – Green – Blue
SDAE	Serviços Distrital das Atividades Económicas
SEAS-OI	Surveillance Environnementale Assistée par Satellite dans l'Océan Indien – Satellite data receptor in La Réunion Island
SOC	Soil Organic Carbon
SPFFB	Serviço Provincial Floresta e Fauna Bravia
SPGC	Serviço Provincial Geografia e Cadastro
SPOT	Satellite Pour l'Observation de la Terre
SRTM	Shuttle Radar Topographic Mission
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VCS	Voluntary Carbon Standard
ZILMP	Zambézia Integrated Landscapes Management Program

General Introduction

1. Context

The Gilé National Reserve (GNR) was long considered as one of the jewels of Mozambique biodiversity. Mainly composed of dry forests called *Miombo*, the GNR housed the last black rhinos population of the country. However, nearly 20 years of civil war devastated the GNR's infrastructures and reduced its wildlife to almost zero.

Since 2009, the *International Foundation for Wildlife Management* (IGF), as part of a co-management agreement with the Mozambican government, has been working to rehabilitate the reserve, restore its infrastructure, reduce poaching and reintroduce animals (buffalo, wildebeest, zebra...). Today, this action is starting to bear fruit and animal populations increase again.

The GNR is now facing two main challenges:

- Find a sustainable source of funding in order to continue the undertaken rehabilitation efforts.
- Work more closely with the local communities living on the outskirts of the Reserve to promote an integrated economic development and reduce deforestation.

Although today the GNR in itself is well managed, local communities still don't see how they can benefit from it and the periphery is experiencing alarming deforestation, as a result of high population growth combined with itinerant "slash and burn" agricultural practices.

To respond to these two challenges, **the Government of Mozambique (GoM) with the support of the *Fonds Français pour l'Environnement Mondial* (FFEM) decided to launch in 2014 a REDD+ pilot project in the GNR**. Its goal is to promote the adoption of conservation agriculture techniques by local communities surrounding the Reserve. It should result in a reduction of deforestation that would generate carbon credits to be sold to international buyers. It would help funding long-term actions with local communities and ease the management of the GNR. **In short, the REDD+ project aims to set up a virtuous circle reconciling economic development and environmental preservation funded by carbon**.

On the basis of that pilot project, **the GoM decided in February 2015 to upscale this REDD+ initiative and to make it an innovative REDD+ jurisdictional program covering 7 districts of Northern Zambézia*: the Zambézia Integrated Landscapes Management Program* (ZILMP)**. An Emission Reduction Project Idea Note (ER-PIN) presenting this initiative was successfully proposed to the Carbon Fund of the Forest Carbon Partnership Facility (FCPF-CF), at its October 2015 session, and the ZILMP is now in the FCPF-CF pipeline. The GoM is now preparing an Emission Reduction Program Document (ER-PD) in order to be able to sell carbon credits to the FCPF-CF. The FCPF-CF Carbon Fund has pledge to buy up to USD50 million in Emission Reductions.

A lot of information from the field is needed to design the content of this program, ranging from carbon data to set the emissions baseline to socio-economic data to fine-tune the activities to be implemented. *Etc Terra* has been involved in the development of the Gilé REDD+ project since January 2014 and has been selected to gather all this data and to propose options and institutional arrangements for the implementation of this broader program.

2. Study area

This study covers seven districts in the Zambézia province: Gilé, Pebane, Maganja da Costa, Mocubela, Ilé, Mulevala and Alto-Molocué (Figure 1). This is the jurisdictional area that the GoM chose to present to the Carbon Fund of the FCPF. The study area covers a total surface of 3.865 million hectares (Table 1).

Table 1: Surface of the ZILMP area

	District Area (ha)	Forest Area 2013 (ha)	Percentage of forest cover
Alto-Molocué	630,812	227,596	36%
Gilé	896,516	543,366	61%
Ilé	303,411	90,147	30%
Maganja da Costa	267,925	94,134	35%
Mocubela	499,234	319,636	64%
Mulevala	261,685	126,358	48%
Pebane	1,005,479	582,546	58%
ZILMP area	**3,865,062**	**1,983,784**	**51%**

The GNR extends over the districts of Pebane and Gilé. It covers 436,400 ha, divided between full protection zone - commonly called the Reserve (283,600 ha) - and a peripheral buffer zone (152,800 ha), where some activities are allowed, located mainly west of the Reserve.

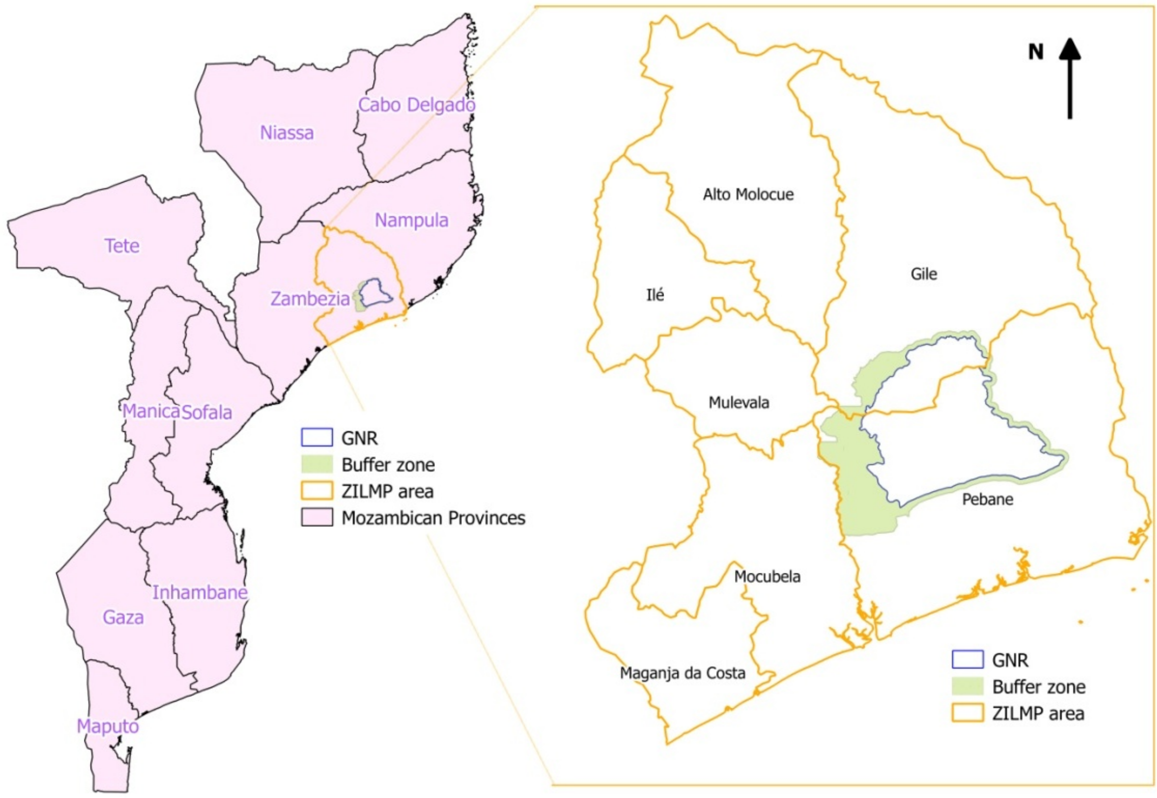


Figure 1: Location of ZILMP area

3. Content of the study

First, this study presents various analyses that are necessary to have a global comprehension of the socio-economic and environmental dynamics in the ZILMP. Then, on that basis, several propositions are formulated for the design of the REDD+ program in terms of activities, institutional arrangements and budget.

The study is structured along the following sections:

1. *Analysis of historical deforestation.* This section aims to map forest extent and deforestation in the ZILMP area over the 1990 – 2013 period on the basis of satellite images.
2. *Analysis of carbon stocks and baseline emissions settings.* This section quantifies the carbon stocks in the Miombo forests of the ZILMP through field inventories. It also sets an emissions baseline, building-on results of the two first sections.
3. *Analysis of the drivers of deforestation and forest degradation*. Thanks to surveys and field visits, this section explains the reasons of deforestation and degradation in the zone, focusing especially on smallholders' agriculture and charcoal production.

4. *Analysis of risks of future deforestation*. This section contains maps of predicted future deforestation, based on historical deforestation and comprehension of the drivers of deforestation.
5. *Options to reduce deforestation and forest degradation*. This section sheds light on a whole set of potential options to reduce deforestation, studied and prioritized in order to design the content of the project. Geography of potential activities is also described.
6. *Institutional arrangements for implementation*. This section proposes key features for the institutional arrangements that will support the implementation of the program.

Analysis of historical deforestation between 1990 and 2013 in the ZILMP area

Analyzing past deforestation is a necessary step to design a meaningful jurisdictional REDD+ program. It helps to better understand past encroachment dynamics and therefore propose a consistent range of options to reduce deforestation. It also enables to set emission baseline and future scenarios based on reliable spatial data.

The objective of this section is **to map forest extent and deforestation over a 23 years period - from 1990 to 2013 - in the 3.9 millions hectares of the Zambézia Integrated Landscapes Management Program.**

This section describes the various steps that have been implemented for the analysis of past deforestation, from the acquisition of satellite images to the final results and interpretations. The document provides a complete set of statistics of deforestation for various perimeters, including the Gilé National Reserve and the overall ZILMP area. A series of maps in both raster (*geotiff*) and vector (*shapefile*) formats as well as an excel spreadsheet containing raw data are available on request.

1. Materials and Methods

1.1. Methodological framework and technical specifications

The methodology for this analysis was determined **so that it is consistent with the methodological frameworks of the FCPF** (FCPF 2013). The methodology is summarized in the following table.

Table 2: Methodological frameworks and description of methodology used by Etc Terra

Satellite images	**LANDSAT images 5, 7 et 8.** Priority use of GLS (*Global Land Survey*) products dedicated to the analysis of land use changes (orthorectified images). In case of unavailability or presence of clouds on these products, archival images L1T (geo-referenced only) will be downloaded.
Dates and periods observed	Images for years *circa* 1990, 2000, 2005, 2010 and 2013. For more consistency, the images acquired in the same season will be preferred. **The period covered goes far beyond standard requirements. Such a period was chosen to have a better understanding of long-term deforestation dynamics.** **FCPF Methodological Framework:** The end date for the Reference Period is the most recent date prior to 2013. The start date for the Reference Period is about 10 years before the end date.
Pre-processing	If the images are not pre-processed (*e.g.* L1T level), a radiometric correction and geometric correction are performed. In case of cloud cover greater than 10% in a part of the study area, technical

	combinations of identical scenes on different dates are implemented to minimize the cloud cover of the final map.
Supervised classification	Use of a supervised classification method (involving the delimitation of training plots and algorithm calibration) and consideration of the 6 IPCC categories of land use (IPCC 2006) and land cover change classes. Visual inspection of *Google Earth* and/or images with very high resolution (2m or better) to assist in the delimitation of these training plots. Use of *ENVI*, *QGIS*, *Grass*, *R* software and *RandomForest* algorithm for classification. **National framework:** Mozambican national REDD+ framework defines the forest according to those criteria: minimum height of 5 meters, minimum tree cover of 30%. Those criteria of height and tree cover are taken into account during the photo interpretation control based on *Google Earth* images.
Post-processing	3 post-processing levels are implemented to clean the map and meet the following Minimum Mapping Units (MMU): - Smoothing through a 3x3 majority filter. - Removal of patch of forests of less than 1 ha. - Removal of patch of deforestation of less than 0.36 ha. **National Framework:** According to Mozambican national REDD+ framework, forest minimum area is 1 ha.
Validation and quality control	**Internal validation**: Random selection of 70% of the training plots for algorithm calibration; the remaining 30% plots were used to generate the confusion matrix and quality indicators. **External validation**: photo-interpretation of forest state on a high-density random sample of points and high-resolution images to cross-validate those reference observations with the map. **Quality control:** Production of a processing chain command script using the dedicated GIS/RS free software (*R*, *Envi*, *Grass*) for checking and reapplying the methodology. **FCFP Methodological frameworks** The Overall Accuracy must be greater than 75%.

1.2. Satellite images database

We only used LANDSAT images to carry out this work in order to ensure uniformity between images and be able to access to archive data over a long period of time – here, 23 years. Furthermore, this type of images is recommended for mapping deforestation as it displays a geometric resolution corresponding to the maximum limit of 30 m required by international REDD+ framework (GOFC-GOLD 2010).

Those images are available on the USGS data servers (*Earth Explorer,* www.earthexplorer.usgs.gov) for free. The images we used come from three different LANDSAT missions (5,7 and 8/OLI) whose sensors are slightly different in terms of width and number of spectral bands. Images were uploaded in bands; therefore, it was primarily necessary to combine these single bands into multispectral images (stacking) for them to be comparable from one date to another. Figure 2 summarizes the necessary characteristics and pairings for the fusion of those different types of images.

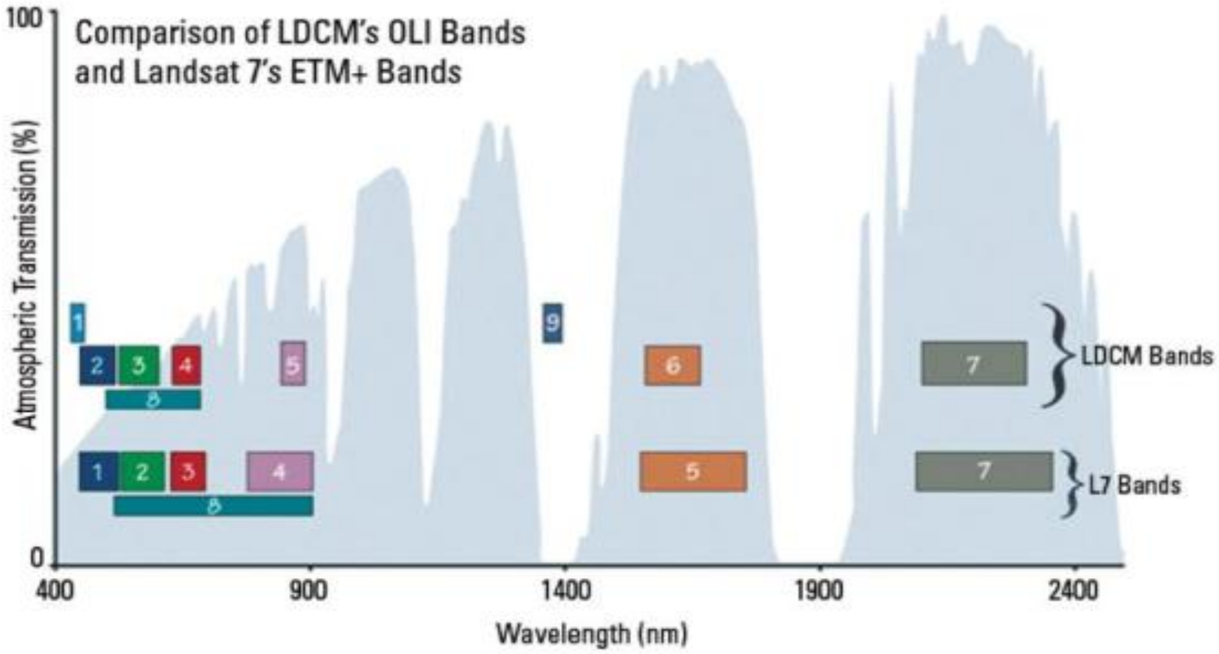


Figure 2: Comparison of spectral bands between LANDSAT 8 (LDCM) and LANDSAT 5/7. LANDSAT 8/OLI collects the same bands as LANDSAT 7 plus two bands 1 and 9 (called bands "cirrus" to improve the atmospheric corrections). Bands 2 to 7 of LANDSAT 8 were renumbered according to Landsat 5-7 numbers, following the color scheme used in this figure. *Source: NASA/USGS*

In addition to those considerations on the different spectral bands characteristics, the choice of images was based on the following criteria:

- Geometric accuracy of less than 1 pixel (visual comparison image per image).
- Presence or absence of effect of the failure of the LANDSAT 7 sensor (stripping effect due to SLC module failure since 2003).
- Cloud and shadow cover.

The study area is covered by four LANDSAT scenes meeting the following identifiers (path/row): 165/071, 165/072, 166/071 and 166/072. The selected and processed LANDSAT scenes are presented in the following table and figure.

Table 3: Date of selected LANDAST images

Scene identification	Reference year of images					Area covered (%)
	~1990 (t1)	~2000 (t2)	~2005 (t3)	~2010 (t4)	~2013 (t5)	
USGS data	GLS 1990	GLS 2000	GLS 2005	GLS 2010	Landsat 8 L1T	

166-071	July-92	Aug-99	June-06	May-09	June-13	22
165-071	July-89	Aug-99	Aug-05	May-10	March-14	36
166-072	July-92	Apr-00	Aug-06	May-09	June-13	13
165-072	July-89	Apr-00	March-05	May-10	March-14	29

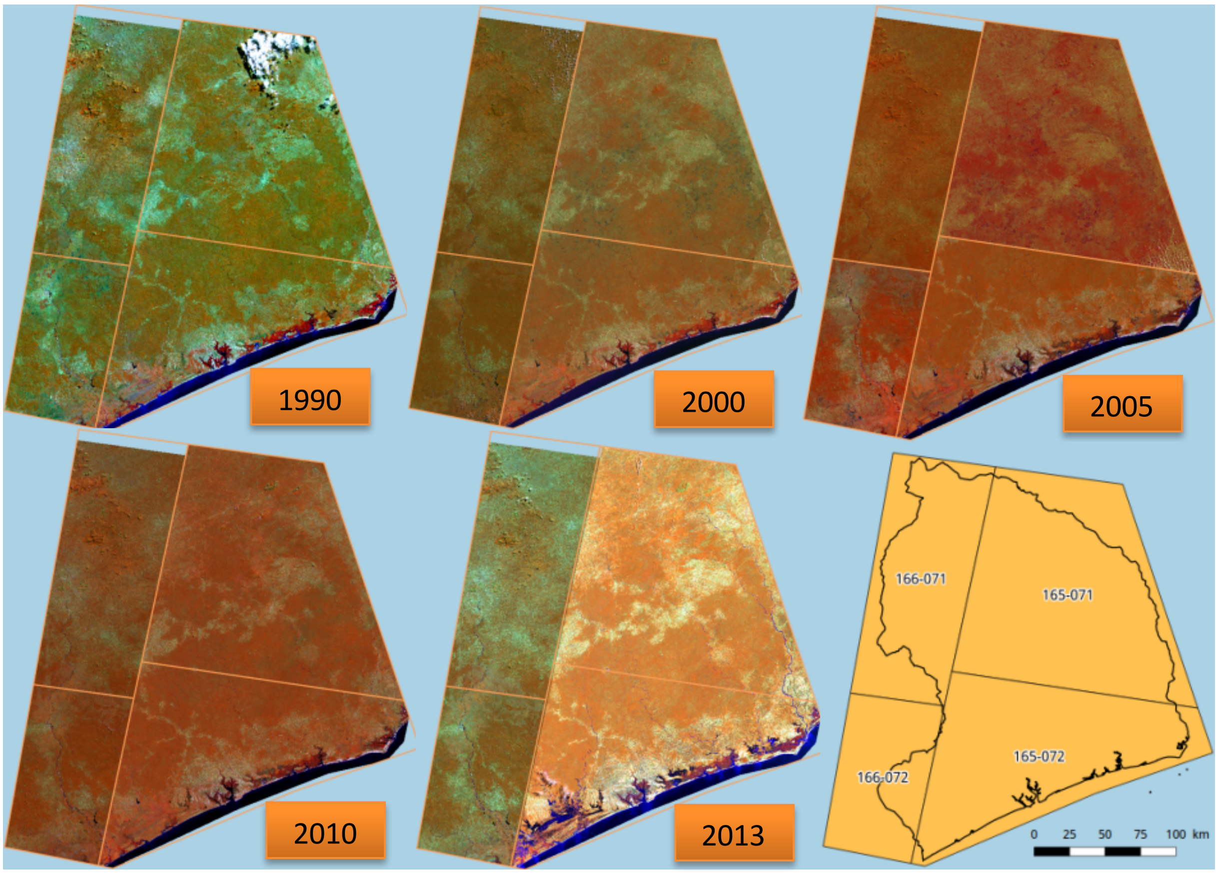


Figure 3: Scope and references of LANDSAT scenes covering the study area. Jurisdiction delimitation is shown on the last map

Data pre-processing purpose is to get a usable image database for a space-time analysis - *i.e.* with little or no cloud cover - a geometric offset between images of less than 1 pixel and little or no stripping effect.

To ensure good geometrical quality images, LANDSAT Global Land Survey products (GLS) and Level-1T (L1T) were used. According to Gutman et al. (2008), these data have sufficient radiometric and geometric qualities to perform land use change analysis.
Additionally, we performed a visual inspection of each scene to check their geometric consistencies. We downloaded different images for the last date (2013) and selected the one that meet the geometric criteria. No additional geo-rectification was performed.

At the end of this control phase, all images showed a discrepancy of less than 1 pixel. The scenes were then combined into mosaics using a contrast adjustment algorithm in order to reduce discrepancies between scenes, caused by contrasted atmospheric conditions. The mosaics are finally produced by reference years over the whole study area.

In order to improve the classification, several spectral indexes were then derived from the primary bands as presented in Table 4.

Table 4: Spectral indexes calculated

Index	Formula
NDVI (*Normalized Difference Vegetation Index*) – Vegetation spectral enhancement	$NDVI = \frac{PIR1 - R}{PIR1 + R}$
NIRI (*Near Infrared Reflectance Index*) – Soil spectral enhancement	$NIRI = \frac{PIR2 - PIR1}{PIR2 + PIR1}$
NDWI (*Normalized Difference Water Index*) – Water spectral enhancement	$NDWI = \frac{PIR1 - V}{PIR1 + V}$

In addition to these reflectance indexes, several others indicators were derived from a Digital Elevation Model (DEM): elevation, slope and topographical roughness. The DEM that was used comes from the USGS data acquired by ASTER satellite (version 3) with a spatial resolution of 30m (Tachikawa et al. 2011).

1.4. Supervised classification

After data pre-processing, the method to establish a deforestation map follows three main steps:

- Definition of land use and land cover changes classes.
- Delimitation of training plots.
- Classification with a specific algorithm.

1.4.1. Definition of land-use classes

Land use and land cover change (LULCC) classes that exist in the program areas and are detectable with Landsat imagery are the following:

- Miombo forest (F).
- Mangroves (M).
- Fallows, savannas and cultivated areas (P).
- Wetlands (H).
- Other lands (bear soils, rocks, settlements) (A).

The analysis of historical deforestation focuses on changes of the two forestland classes: mangroves and Miombo forest. According to methodological frameworks (FCPF 2013), it is required to study at least raw deforestation, that is to say, conversion from forest land to other land.

In line with the GOFC-GOLD REDD sourcebook (GOFC-GOLD 2010), we applied a “pre-classification method” of land cover changes, instead of a “post-classification” (combinations of independent maps). Such a method should reduce the error in deforestation estimations, as it does not multiply the errors from the independent maps. In practice, this implies to identify stable and dynamic land cover on the multi-date stack of images at a same stage. Hence, the typology presented in the following table was adopted.

Table 5: Typology of land use & land cover changes classes for the study

Numeric code for the map	Identification code in the training plots database	Description of the class
11111	FFFFF	Forest remaining forest over the 1990-2013 period
11113	FFFFP	Forest converted to fallow/cultivated land between 2010-2013
11133	FFFPP	Forest converted to fallow/cultivated land between 2005-2010
11333	FFPPP	Forest converted to fallow/cultivated land between 2000-2005
13333	FPPPP	Forest converted to fallow/cultivated land between 1990-2000
33333	PPPPP	Mosaic of cropland, fallow and savannah land since 1990
44444	HHHHH	Wetland
66666	AAAAA	Rocks, bare soil and sand
77777	MMMMM	Mangrove forest in 2013

1.4.2. Delimitation of training plots

Delimitation of trainings plots is a necessary step to calibrate the classification algorithm when applying a supervised classification. The accuracy of the classification mainly depends on the quality of the delimitation of these training plots. Therefore, a standardized and rigorous photo-interpretation work was conducted. Photo-interpretation was carried on the basis of field knowledge, LANDSAT images patterns and high-resolution images from *Google Earth*. Number of polygons and area delimitated are presented in the table below.

Table 6: Number of polygons and associated delimitated area used as training plots

LULCC Class ID	Number of training polygons	Cumulated area (ha)
AAAAA	42	148.9

FFFFF	174	471.8
FFFFP	78	131.6
FFFPP	45	85.9
FFPPP	76	227.7
FPPPP	81	310.9
HHHHH	45	177.3
MMMMM	26	101.2
PPPPP	162	742.5
Total	729	2397.7

First, in order to improve the localization and determination of changes, those areas were highlighted by performing a multi-dates color composite (Figure 4). Then, training plots were located in cluster - *i.e.* by grouping several plots of different categories on a same landscape unit or small area (Figure 5). A landscape unit is defined according to the scale of study: here, it roughly represents an area of analysis below 3 km^2 and/or at 1:10 000 scale. In order to reduce noise in training data and to guarantee the appropriate consideration of the forest definition, plots contours were verified by superposition on very high-resolution images available on *Google Earth*. Those images can be originated either by *Quickbird* or *Ikonos* satellites, with ground resolution around 0.6 meters.

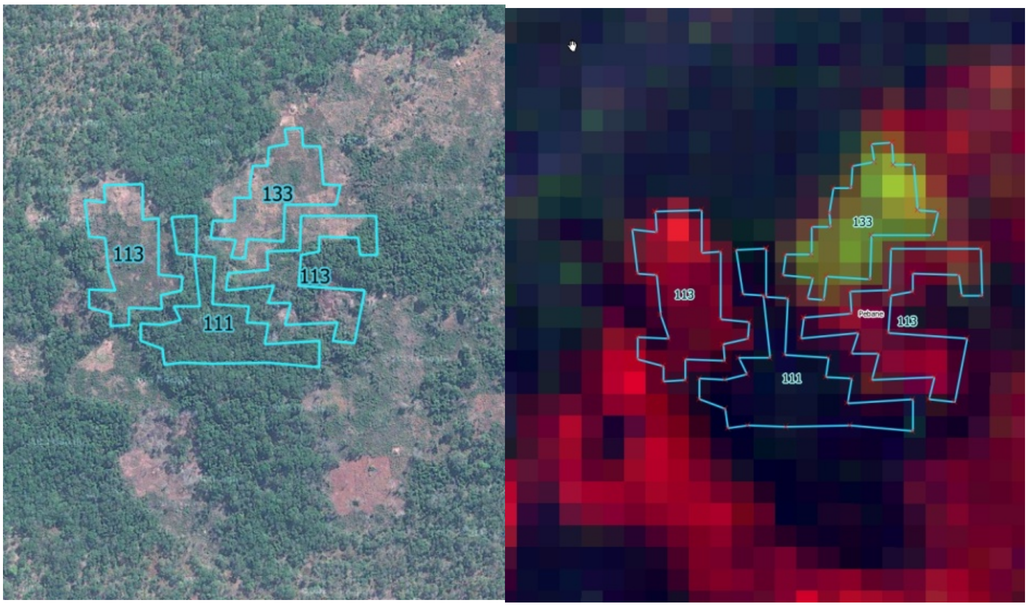


Figure 4: Example of multi-dates colorized composition showing several LULCC classes on the right (R: Band5-2013; G: Band5-2010; B: Band5-2005). Deforestation between 2005 and 2010 appears in green while deforestation between 2010 and 2013 appears in red. Forests staying forests are in blue and dark green. On the left, plots are overlaid on *Google Earth* image (*Quickbird* acquired the 12/08/2013)

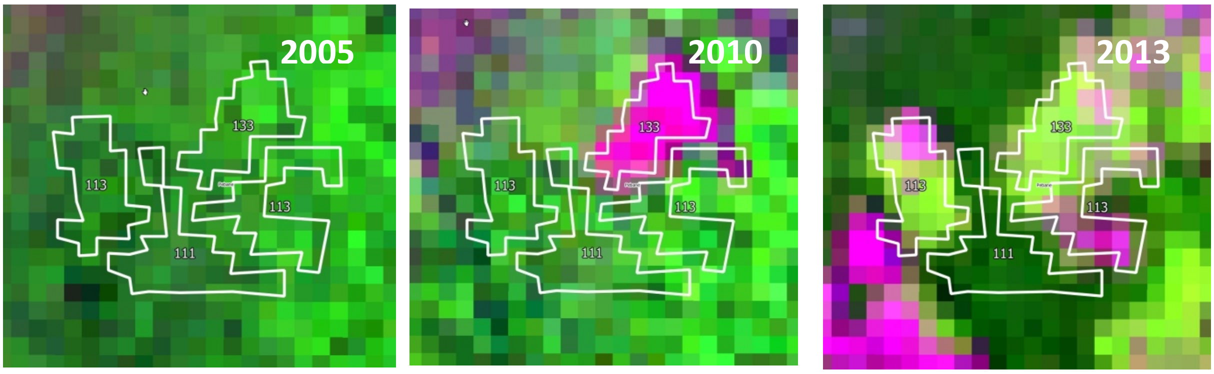


Figure 5: Example of training plot delimitation and LULCC category determination on 2005, 2010 and 2013 images (false color composite: R: Band5; G: Band4; B: Band3). The band numbers correspond to the band number of Landsat 5-7 sensor, the band number of LANDSAT 8-OLI were renumbered according to figure 2.

1.4.3. Classification

Afterward, the training plot spatial database was correlated with the multi-date stacked image database using a statistical algorithm. In order to do so, we used the *RandomForest* algorithm, developed by Breiman (2002) and available in *R* software. It is a data-mining algorithm that combines bugging techniques and decision tree (Figure 6). It was successfully applied in similar land cover change studies in tropical forest (Grinand et al. 2013) and more recently in the Miombo forest biome (Kamusoko, Gamba, and Murakami 2014).

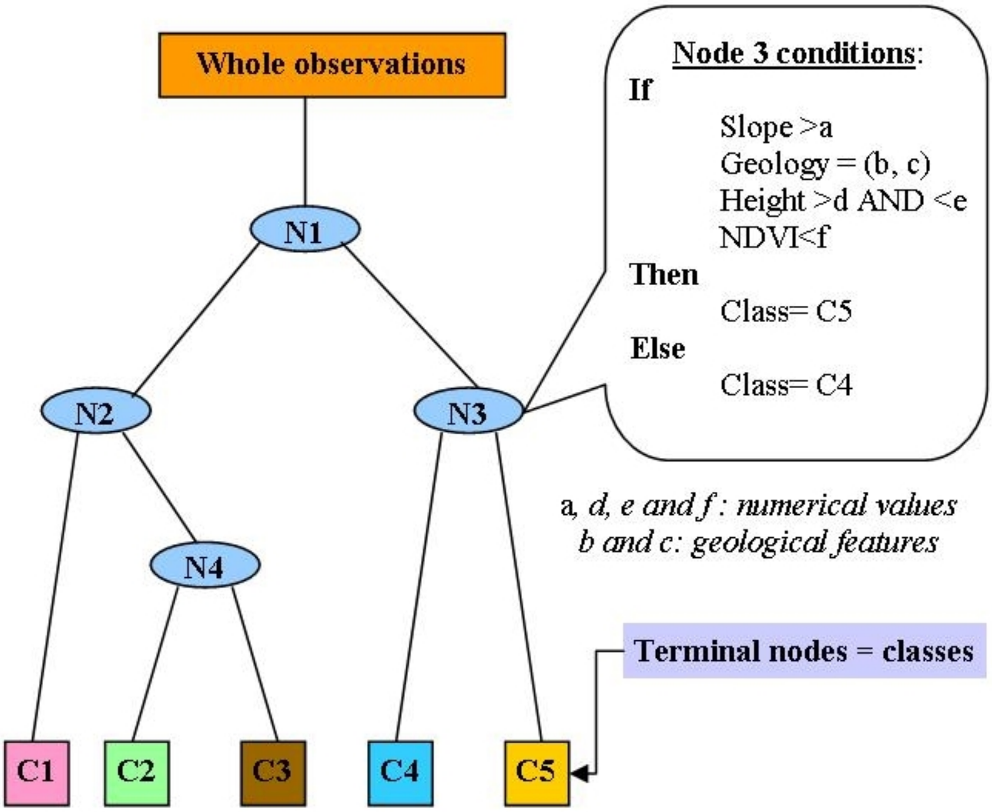


Figure 6: Classification principle with decision tree analysis. *RandomForest* uses and completes this principle by creating a large number of small decision trees by random selection of individuals (bagging), and affecting at a majority vote in order to determine the final category.

RandomForest calibration was performed using 2/3 of randomly selected training plots. The remaining plots (1/3) were used to perform an "internal validation". Based on a confusion matrix, this validation enabled the operator to identify the remaining confusions in order to add, remove or change the training plots on the GIS and redo the classification until satisfactory results were obtained. At this stage, we usually considered as acceptable commission errors of less than 10% and 20% for, respectively, stable land cover category and land cover change category.

1.5. Post-classification treatments

After classification, some isolated pixels of forest were found, giving a noisy appearance to the map. To respect the requirements on MMU (linked to the forest definition), those pixels were removed during post-classification processing. In the present study, MMU is 1 ha for forest and 0.36 for deforestation.
A majority filter with a 3x3 window was first used to remove isolated pixels. The classified image was filtered with a *Grass/R* script for forests and deforestation patches.

1.6. External validation of results

This step entails a statistical analysis of the classification results accuracy, with a points sampling approach. Those validation points were selected independently of training plots that were used for the classification.

The sample scheme involved the creation of 5 km wide grids that over the the study area. We selected 20 grids randomly. On those grids, points were evenly spaced apart, every 100 m (see the figure below). At the end, the validation sampling dataset represented a total of 50 000 validations points. The state of the forest was visually inspected on every point and gathered in a spatial database. The inspections were based on very high-resolution *Google Earth* images and on the LANDSAT images that had been used for the classification. The result of the photo-interpretation (reference dataset) was finally compared with the map to produce a confusion matrix. This confusion matrix is used to calculate the accuracy of the map (see method Annex 1: Confusion matrix calculations).

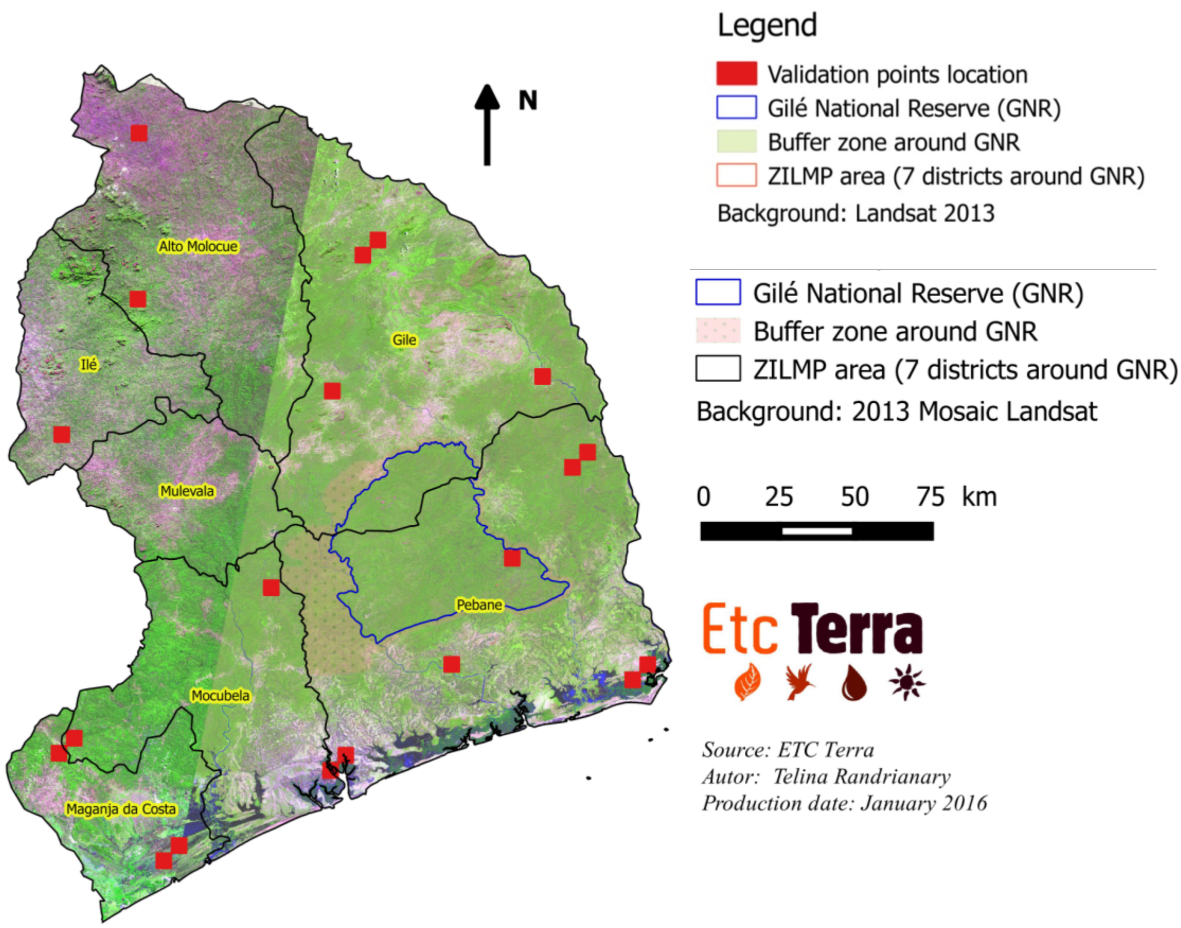


Figure 7: Distribution of the 20 grids randomly selected for the sampling of validation points in the study area

1.7. Deforestation rate calculation

Usually, the annual deforestation rate is defined as a ratio between the deforestation area over a period and the number of years covered by this period (Menon and Bawa 1997).

However, several publications explained that this simple ratio was actually not relevant, since deforestation rate dynamics depend follows a compound interests rule: as deforestation continues, forest area changes and the ratio (Puyravaud 2003). Hence, an adaptation of this law was done to calculate annual deforestation rate.
The following standardized equation proposed by Puyravaud (2003) was used in the present study:

Equation 1

$$\boldsymbol{\theta = -\frac{1}{t2 - t1}\, ln\frac{A2}{A1}}$$

Where
θ is the deforestation rate in the study area
A_i is the forest area during the year t_i

This calculation approach requires knowing exactly the interval between the two dates (t1 and t2) of the period under review. Therefore, a table summarizing the exact intervals between images of the mosaic was established (Table 7). When several images are combined into a mosaic for the classification, the overall annual deforestation rate for a specific study area is the weighted sum of the several calculated annual rates. The weighting coefficient is the ratio between forest area of the image of interest and the forest area of the total study area (see Annex 2: Example of weighted deforestation rate calculation). To summarize, the calculation of global deforestation rates is completed with the following equations.

Equation 2

$$\theta_r = \sum_{i=1}^{n} \omega_i . \theta_i$$

Where
θ_r is the deforestation rate of the study area
θ_i is the deforestation rate for the LANDSAT scene i
ω_i is the weighting coefficient
n is the number of LANDSAT scenes covering the study area

And

Equation 3

$$\omega_i = \frac{S_i}{S_T} \text{ with } \sum \omega_i = 1$$

Where
S_T the forest area of the overall study region (at date t1)
S_i the forest area on the LANDSAT scene i $(S_T=S_1+S_2+...+S_N)$

Table 7: Time interval between reference years

Scene identification	Time interval (decimal year)			
	1990-2000	2000-2005	2005-2010	2010-2013
166-071	7.1	6.8	3	4
165-071	10.1	6	4.8	3.8
166-072	7.8	6.3	2.8	4.1
165-072	10.8	4.9	5.2	3.8
Average	**9**	**6**	**3.9**	**3.9**

2. Results

2.1. External validation of classification results

Overall, we photo-interpreted 49,942 plots on LANDSAT/*Google Earth* and checked their respective classification on our result map in order to build a confusion matrix, presented in Table 8 and Table 9 below. The 58 missing points were outside the land area (*ie* in the sea).

Table 8: External validation confusion matrix

		Reference dataset (Photo-interpreted categories)									
		11111	11113	11133	11333	13333	33333	44444	66666	77777	Total
Deforestation map (predicted categories)	11111	21,032	405	261	285	226	1675	133	0	25	24,042
	11113	66	558	77	24	23	33	0	0	0	781
	11133	16	13	284	71	19	25	0	0	0	428
	11333	46	32	138	479	57	73	2	5	0	832
	13333	120	28	51	107	700	78	2	4	1	1,091
	33333	1,153	216	174	208	361	12,425	728	2,065	80	17,410
	44444	5	1	1	0	0	11	1,488	2	10	1,518
	66666	0	0	0	0	0	43	0	45	0	88
	77777	9	0	4	0	0	1	343	1	3,394	3,752
	Total	22,447	1,253	990	1,174	1,386	14,364	2,696	2,122	3,510	49,942

Table 9: Confusion matrix, proportion and uncertainty

	Reference dataset (Photo-interpreted categories)													
		11111	11113	11133	11333	13333	33333	44444	66666	77777	Total	User accuracy	Commission error	90% relative margin of error (%)
Map categories	11111	42.1	0.8	0.5	0.6	0.5	3.4	0.3	0.0	0.1	0.48	0.87	0.13	0.4
	11113	0.1	1.1	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.02	0.71	0.29	2.7
	11133	0.0	0.0	0.6	0.1	0.0	0.1	0.0	0.0	0.0	0.01	0.66	0.34	3.7
	11333	0.1	0.1	0.3	1.0	0.1	0.1	0.0	0.0	0.0	0.02	0.58	0.42	2.8
	13333	0.2	0.1	0.1	0.2	1.4	0.2	0.0	0.0	0.0	0.02	0.64	0.36	2.4
	33333	2.3	0.4	0.3	0.4	0.7	24.9	1.5	4.1	0.2	0.35	0.71	0.29	0.6
	44444	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.03	0.98	0.02	0.6
	66666	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.00	0.51	0.49	8.8
	77777	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	6.8	0.08	0.90	0.10	0.8
	Total	0.45	0.03	0.02	0.02	0.03	0.29	0.05	0.04	0.07	1.00			
	Producer accuracy	0.94	0.45	0.29	0.41	0.51	0.87	0.55	0.02	1.00				
	Omission error	0.06	0.55	0.71	0.59	0.49	0.13	0.45	0.98	0.00				
	Overall accuracy										0.81			

An overall accuracy of **81%** means that 81% of the **49,942** photo-interpreted points were successfully classified thanks to our algorithm.

Despite the difficulties due to the diversity of forest spectral responses in the study area, **the resulting overall accuracy of 81%** (Kappa index is 0.72) confirms the acceptability of the classification results. This is supported by a good distribution of validation points in the study area. In addition, the overlaying of our map on a *Google Earth* image supports the fairly high value of the overall accuracy. Regarding the user accuracy per class, the average value for all deforestation classes is 0.7, except for the deforestation between 2000 and 2005 class (code 11333), which is 0.58. A user accuracy value of 0.87 is obtained for the forest category.

These results are consistent with the values obtained in other similar studies, such as (Grinand et al. 2013). The FCPF Carbon Fund Methodological Framework (FCPF 2013) requires that uncertainties be indicated as a two-tailored 90% confidence interval (indicator 9.1). We thus estimated the 90% relative margins (Table 9), which are all below 3%, except for the mangrove class (8.8%). This value leads to the estimation of the 90% confidence interval in hectares for each class.

2.2. Mapping results

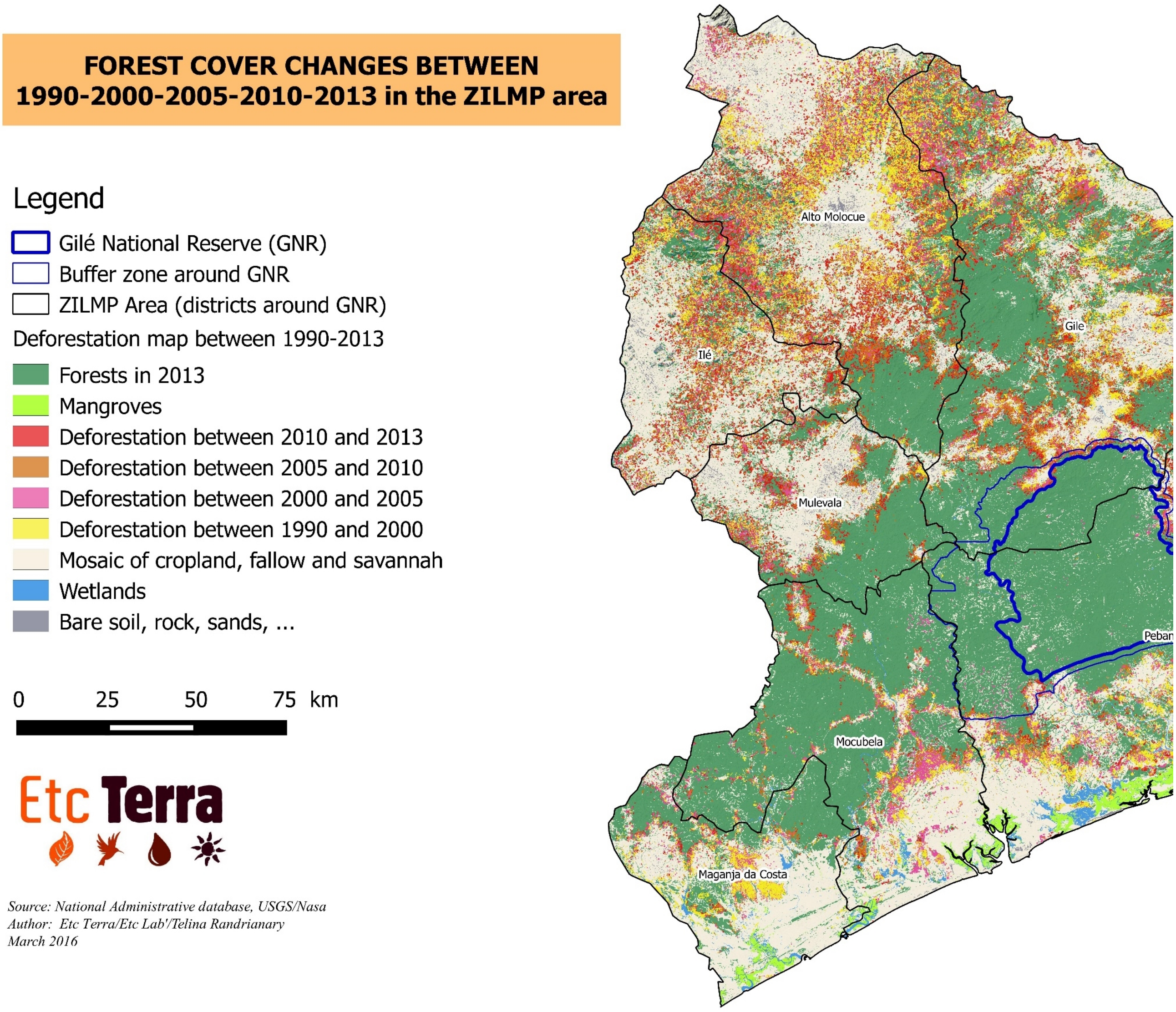


Figure 8 and Figure 9 below show the final deforestation maps for, respectively, the ZILMP area and the GNR and its buffer zone. All maps are also delivered in JPEG format, as well as raw raster data for potential further analysis.

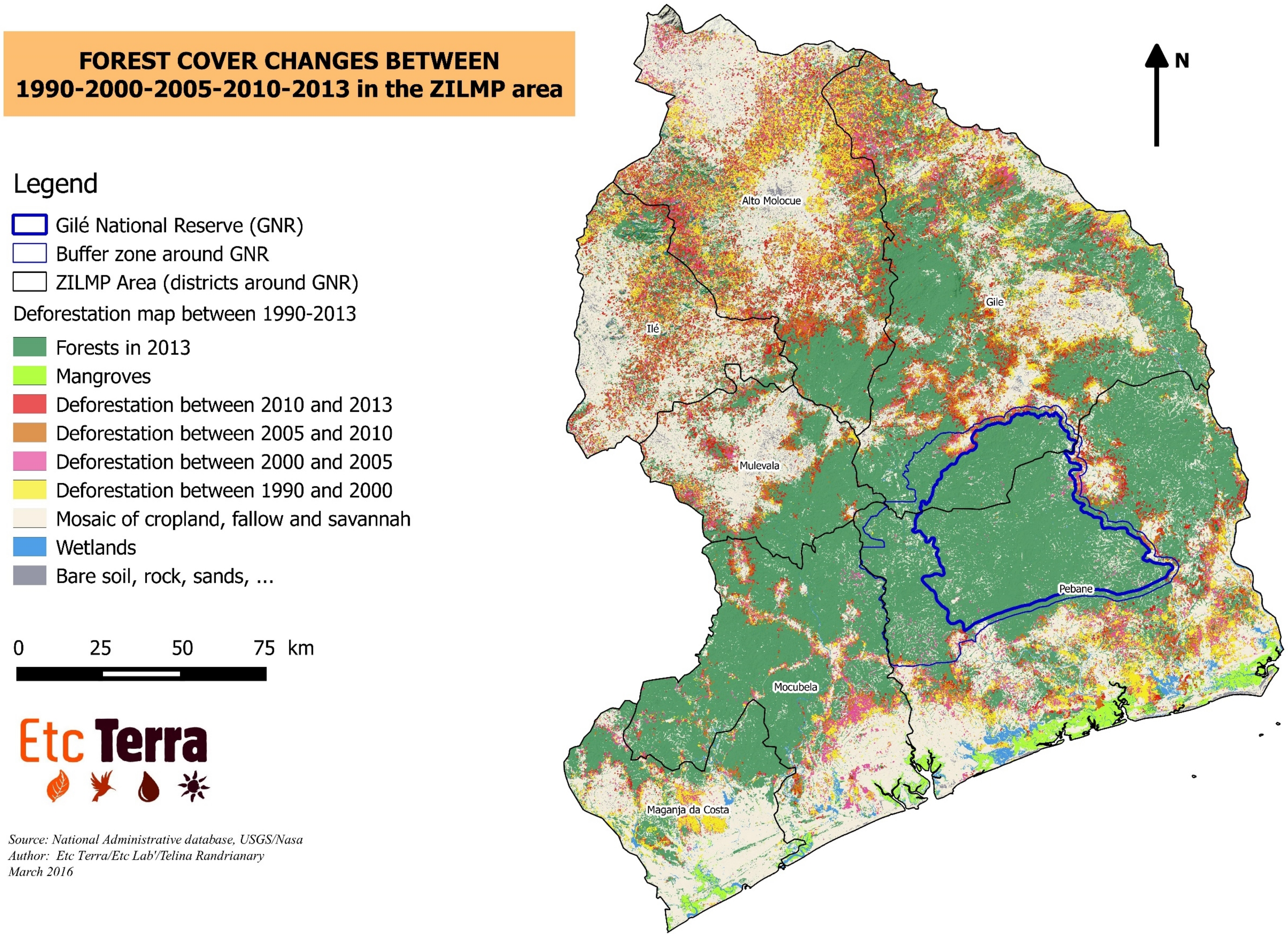


Figure 8: Deforestation between 1990 and 2013 in the ZILMP area

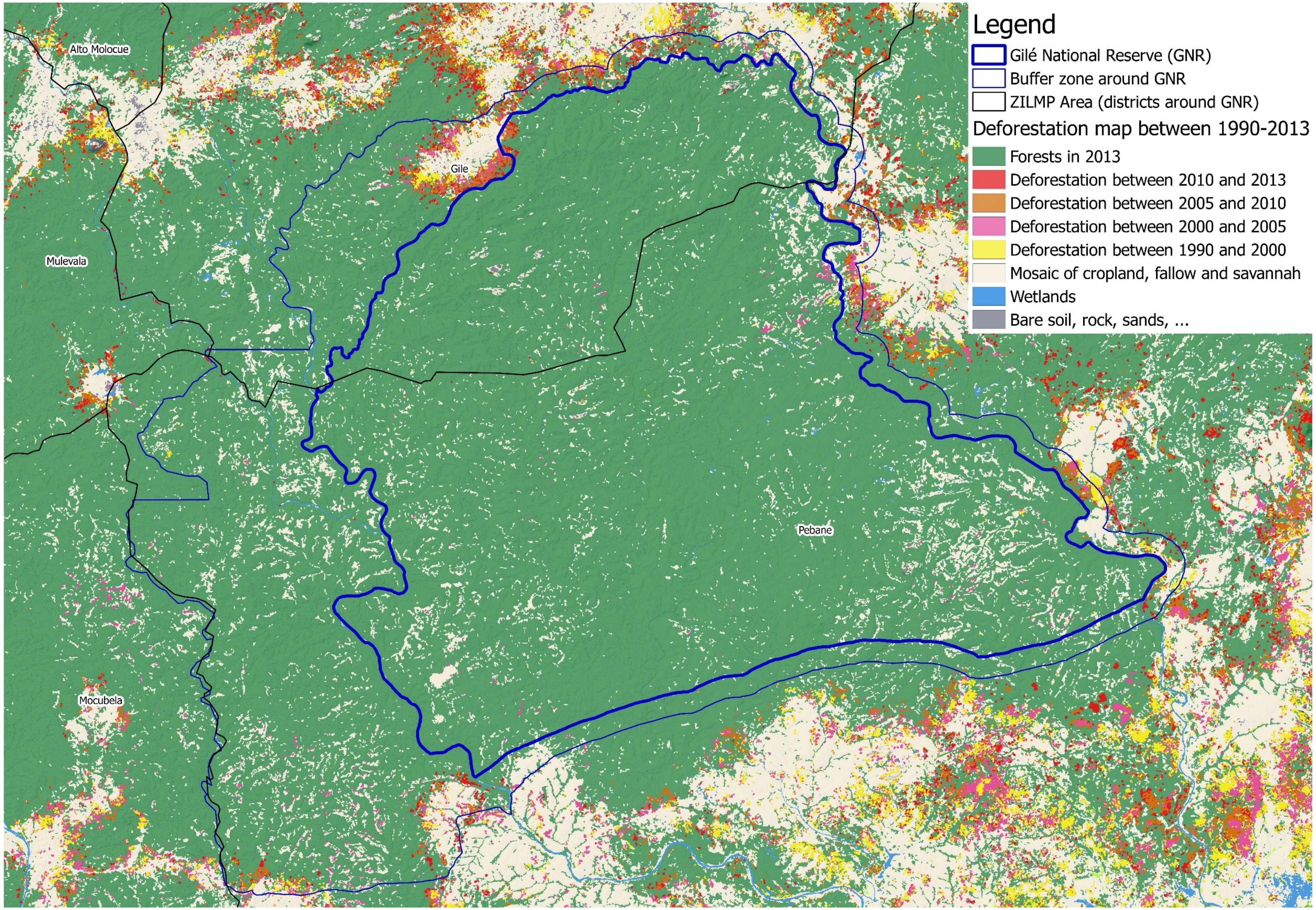


Figure 9: Deforestation between 1990 and 2013 in the GNR and its buffer zone

2.3. Forest statistics

Table 10, Table 11 and Table 12 below show forest statistics in the ZILMP area for various time frames and geographical demarcations: the whole ZILMP area, its districts, the GNR, its buffer zone. Mangroves statistics are also shown.

Table 10: Forest areas

	Forest area [ha]					
	Forest 1990	*Forest 2000*	*Forest 2005*	*Forest 2010*	*Forest 2013*	*Forest loss 1990 - 2013*
Alto-Molocué	**309,071**	**274,574**	**259,960**	**248,594**	**227,596**	**- 26%**
Gilé	**627,397**	**593,964**	**581,217**	**563,446**	**543,366**	**- 13%**
Ilé	**114,000**	**105,797**	**102,624**	**98,573**	**90,147**	**- 21%**
Maganja da Costa	**110,322**	**101,559**	**96,501**	**95,394**	**94,134**	**- 15%**
Mocubela	**344,573**	**337,313**	**327,213**	**321,893**	**319,636**	**- 7%**
Mulevala	**138,214**	**135,771**	**133,979**	**130,731**	**126,358**	**- 9%**
Pebane	**650,001**	**621,058**	**603,705**	**591,930**	**582,546**	**- 10%**
Total 7 districts	**2,293,577**	**2,170,035**	**2,105,198**	**2,050,560**	**1,983,784**	**- 14%**
Gilé National Reserve	**262,145**	**262,049**	**261,718**	**261,642**	**261,556**	**0%**
Buffer zone	**128,241**	**127,062**	**125,831**	**124,159**	**122,917**	**- 4%**
GNR + Buffer Zone	**390,346**	**389,072**	**387,510**	**385,759**	**384,431**	**- 2%**
Mangroves	**53,361**	**53,353**	**53,353**	**53,349**	**53,348**	**0%**

Table 11: Forest Loss

	Annual forest loss [ha/year]					
	1990-2000	*2000-2005*	*2005-2010*	*2010-2013*	***1990-2013***	***2005-2013***
Alto-Molocué	3,958.5	2,306.3	2,857.5	5,376.5	3,532.9	4,105.5
Gilé	3,311.5	2,139.9	3,739.2	5,268.5	3,413.6	4,419.8
Ilé	1,127.2	468.9	1,330.3	2,096.6	1,129.2	1,766.3
Maganja da Costa	931.4	916.4	273.3	320.0	707.5	296.3
Mocubela	703.5	1,985.9	1,106.8	585.9	1,037.2	875.1
Mulevala	261.4	301.8	752.6	1,127.9	503.5	930.2
Pebane	2,757.8	3,255.4	2,360.5	2,462.3	2,740.0	2,404.6
Total 7 districts	**13,051.4**	**11,374.6**	**12,420.2**	**17,237.6**	**13,063.8**	**14,797.7**
	Annual forest loss [ha/year]					
	1990-2000	*2000-2005*	*2005-2010*	*2010-2013*	***1990-2013***	***2005-2013***
Gilé National Reserve	**9.2**	**60.5**	**15.4**	**22.6**	**23.9**	**18.5**
Buffer Zone	**111.6**	**236.6**	**331.7**	**326.0**	**216.3**	**329.2**
GNR + Buffer Zone	**121.9**	**290.1**	**352.1**	**348.6**	**240.3**	**350.6**
Mangroves	**0.7**	**0**	**0.8**	**0.2**	**0.5**	**0.5**

Table 12: Deforestation rates

	Annual deforestation rate [%]					
	1990-2000	*2000-2005*	*2005-2010*	*2010-2013*	***1990-2013***	***2005-2013***
Alto-Molocué	**1.50**	**0.84**	**1.19**	**2.25**	**1.35**	**1.69**
Gilé	**0.54**	**0.36**	**0.65**	**0.95**	**0.58**	**0.79**
Ilé	**1.04**	**0.45**	**1.34**	**2.22**	**1.12**	**1.84**
Maganja da Costa	**0.88**	**0.98**	**0.28**	**0.33**	**0.68**	**0.31**
Mocubela	**0.20**	**0.62**	**0.33**	**0.18**	**0.31**	**0.27**
Mulevala	**0.21**	**0.21**	**0.63**	**0.87**	**0.39**	**0.71**
Pebane	**0.43**	**0.57**	**0.39**	**0.42**	**0.44**	**0.41**
Total 7 districts	**0.60**	**0.55**	**0.61**	**0.86**	**0.61**	**0.70**
Gilé National Reserve	**0.004**	**0.023**	**0.006**	**0.009**	**0.009**	**0.01**
Buffer zone	**0.09**	**0.18**	**0.28**	**0.27**	**0.17**	**0.26**
GNR + Buffer zone	**0.032**	**0.073**	**0.094**	**0.091**	**0.06**	**0.09**
Mangroves	**0.0017**	**0.0000**	**0.0015**	**0.0003**	**0.0009**	**0.001**

A first observation is that forest is still the dominant land cover category in the zone: it covers 51% of the ZILMP area. The situation is very different between (i) the northern districts and (ii) the southern and eastern ones: whereas forest cover is 60% in Pebane, Mocubela and Gilé, it only achieves a rate of 30% to 36% in Ilé and Alto Molocué.

Besides this observation, the ZILMP area had suffered important deforestation, losing nearly 310,000 ha in 23 years, between 1990 and 2013 – this is an annual deforestation rate of **0.61%**. Unfortunately, deforestation rate is increasing since 2000, reaching 0.86% for the most recent period (between 2010 and 2013).

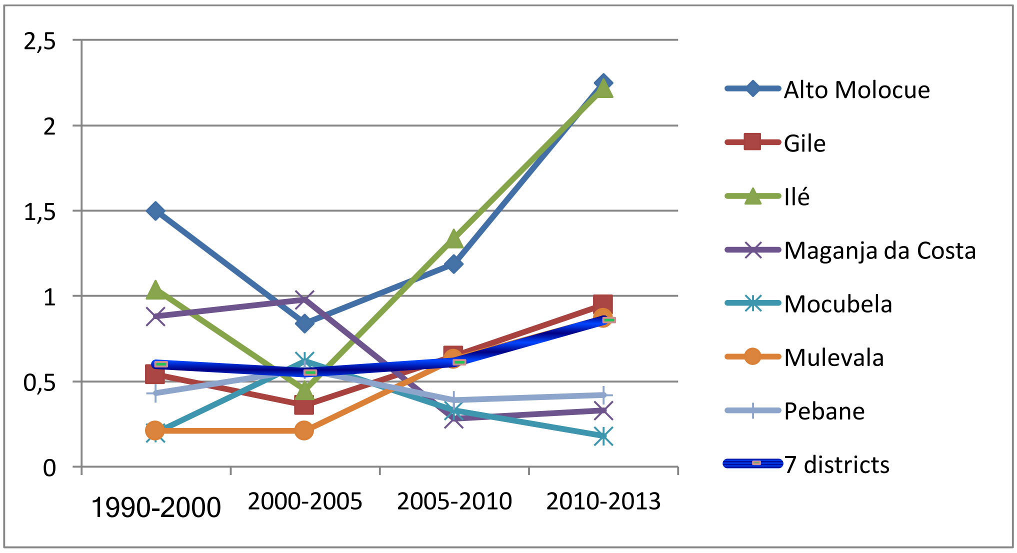


Figure 10: Annual deforestation rate by district over the 1990 – 2013 period

Statistics clearly differ from one district to the other, deforestation being more intense in districts that are far from the Reserve. The districts of Alto-Molocué and Ilé show the highest deforestation rate values, especially during the penultimate (2005-2010) and ultimate (2010-2013) periods. Between 2005 and 2010, the annual rates of deforestation are 1.19% and 1.34% for, respectively, Alto-Molocué and Ilé. They increase up to, respectively, 2.25% and 2.22% between 2010 and 2013.

On the other hand, annual deforestation rate in the other districts is less than 1% for all the periods under review. Furthermore, the analysis of the minimum and maximum values of deforestation shows that the lowest deforestation rate is that of the district of Mocubela, which is limited to 0.20% between 1990 and 2000. It should be noted that the headquarters of Renamo during the war was in the district Mocubela: significant movements of people fleeing the area may explain lower rates. The maximum value is observed in the district of Alto-Molocué, reaching 2.25% between 2010 and 2013.

Looking at the statistics in the Reserve, very low annual deforestation rates are stated: they average 0.009% between 1990 and 2013. However, values are more alarming considering the buffer zone: although deforestation rate is 0.17% in average between 1990 and 2013, it is 0.28% between 2005 and 2013. There is therefore a growing threat around the Reserve, even if we observed a recent stabilization that may be due to management improvement since 2009.

To sum up, although the forest in the Gilé National Reserve is still preserved, it may soon be affected by land clearing activities, which are increasing on its periphery. Our maps also show a new deforestation frontier in the north of the Reserve near Namurrua. Deforestation rates in the buffer zone are increasing year after year, especially in the northern and northwestern part of the Reserve.

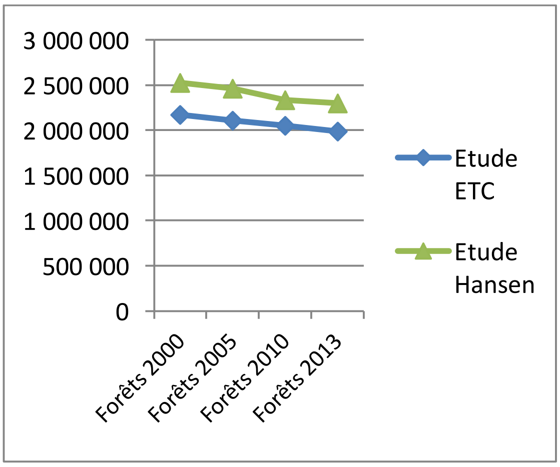
For the entire ZILMP area, over the FCPF 2005 – 2013 reference period, annual deforestation rate is 0.70% and the annual forest loss is **14,798 ha**. As requested by the FCPF standard, we calculated a 90% confidence interval of ± 293 ha. This figure will be used to set the baseline.

We did not observe any deforestation in mangroves: only 13 ha of 53,361 ha were lost between 1990 and 2013. This result is coherent with a recent publication by Shapiro et al. (2015) showing an increase of the mangroves surface in the Zambezi Delta between 1994 and 2013.

2.4. Comparison with Hansen data

Compared with Hansen data (Hansen et al. 2013), statistics differ both in terms of forest area and annual rate of deforestation: this is due to a significant difference in methodology, especially in the post-processing. Forest areas obtained in this study differ by about 15% from Hansen data (forest being defined by applying a threshold of 30% in the treecover 2000 layer) while differences on rates of deforestation depend on the period and on the geographical demarcation – a 100% difference is even reached between 2005 and 2010 for the whole program area. On this specific point, our data seem closer to reality as they show a tendencial increase of the deforestation rate over time, in line with population increase, whereas Hansen data show a peak during the 2005 – 2010 period. Both sets of data agree on the fact that the districts of Alto Molocue and Ilé have the highest deforestation rates.

Regarding those differences, it should be noted that Hansen forestry data is partly biased. First, the forest area is defined by an arbitrary threshold on the forest cover layer (*treecover* product). This layer does not correspond to a forest cover that would have been measured in the field: it is therefore very difficult to find the value corresponding to the actual forest / non-forest limit. Second, deforestation data is defined by an algorithm globally applied to detect brutal falls in vegetation indices, which are interpretated by the algorithm as deforestation. Althouhg it is efficient, this method does not take into account the local definition of forest (minimum height and canopy cover). In addition, Hansen data start from 2000, therefore confusion between natural forest clearing (Miombo) and secondary forest (cleared before 2000) are common. Finally, this data is not validated in the field. **The comparison with our results is therefore presented for information only.**



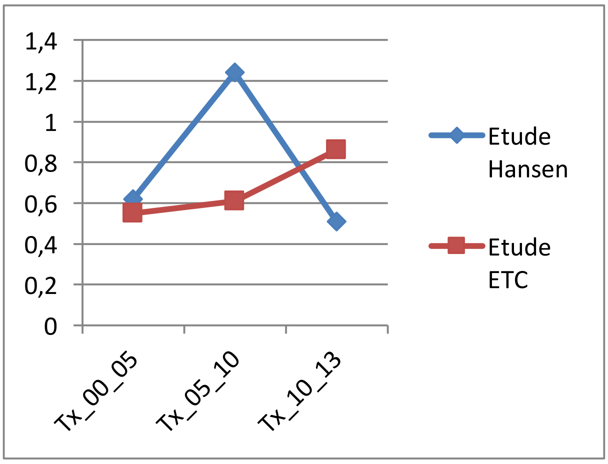


Figure 11: Comparison between the study's results and Hansen's for forest areas (left, in ha) and deforestation rate (right, in %/year)

Table 13: Forest and Deforestation statistics from Hansen

	Forest Area (ha)				**Deforestation (ha)**			
	Forest 2000	**Forest 2005**	**Forest 2010**	**Forest 2013**	**2000-2005**	**2005-2010**	**2010-2013**	**2005-2013 [ha/year]**
Alto-Molocué	379,926	363,149	338,543	331,521	16,777	24,606	7,022	3,953.50
Gilé	666,803	653,189	626,650	618,386	13,614	26,539	8,264	4,350.38
Ilé	128,192	120,304	107,745	104,631	7,888	12,559	3,114	1,959.13
Maganja da Costa	149,748	145,987	138,509	137,394	3,761	7,478	1,115	1,074.13
Mocubela	368,867	364,102	351,468	349,004	4,765	12,634	2,464	1,887.25
Mulevala	137,993	133,940	123,646	121,989	4,053	10,294	1,657	1,493.88
Pebane	692,723	678,455	648,739	639,094	14,268	29,716	9,645	4,920.13
Total 7 districts	2,524,252	2,459,126	2,335,300	2,302,019	65,126	123,826	3,3281	**19,638.38**
Gilé National Reserve	260,788	260,668	260,263	259,988	120	405	275	85.00
Buffer Zone	130,404	130,288	130,023	129,879	116	265	144	51.13
GNR + buffer zone	391,192	390,956	390,286	389,867	236	670	419	136.13

Table 14: Annual deforestation rates from Hansen

	Annual deforestation rate (%)			
	2000-2005	2005-2010	2010-2013	2005-2013
Alto-Molocué	0.903	1.403	0.699	1.089
Gilé	0.413	0.830	0.443	0.666
Ilé	1.270	2.205	0.978	1.628
Maganja da Costa	0.509	1.052	0.269	0.736
Mocubela	0.260	0.706	0.235	0.518
Mulevala	0.596	1.599	0.450	1.115
Pebane	0.416	0.896	0.499	0.725
Total 7 districts	0.52	1.01	0.48	0.799
Gilé National Reserve	0.009	0.031	0.035	0.033
Buffer Zone	0.02	0.041	0.037	0.039
GNR + Buffer Zone	0.012	0.034	0.036	0.035

3. Conclusion

This study focused on the historical analysis of deforestation of **the 7 districts of the *Zambézia Integrated Landscapes Management Program*** (Gilé, Pebane, Alto-Molocué, Mulevala, Maganja da Costa, Ilé and Mocubela) **between 1990 and 2013**. A supervised and multi-temporal analysis of LANDSAT satellite images was used to produce deforestation maps for the period considered.

An intensive process of external validation using a sample of regular points was conducted to produce quality indicators and assess uncertainty as requested by the FCPF methodological frameworks. **The overall accuracy of 81% reflects the good quality of our multi-temporal classification and is above standards requirements**.

Outputs of this study include statistics on forest areas and annual deforestation rates. For the entire ZILMP area, **over the 2005 – 2013 period (FCPF reference period), annual deforestation rate is 0.70% and the annual forest loss is 14,798 ha ± 293 ha, with a 90% confidence interval**.

Over the same period, deforestation dynamics per district have been very different, with deforestation rates ranging from 0.27% to 1.69%, illustrating different socio-economical dynamics. **Globally, deforestation tends to increase steadily since 2000**.

Today, the Gilé National Reserve is still preserved from deforestation with an annual rate of deforestation of 0.01% over the reference period. Nevertheless, the GNR is at risks as we observe a new deforestation front in the Northwest of the Reserve and as deforestation in the buffer has been increasing since 1990 (from 0.09% to 0.27%) – despite a recent stabilization.

We do not observe any deforestation in mangroves: only 13 ha of 53,361 ha were lost between 1990 and 2013.

Analysis of carbon stocks and setting of the emissions baseline

The development of REDD+ program implies establishing a reference emission level (REL). For this purpose, in addition to the analysis of historical deforestation as presented in the previous section, it is necessary to develop emission factors. For deforestation, they can be estimated from carbon stocks of various pools of forests and post-deforestation strata. **The objective of the present section is to estimate those carbon stocks and assess the resulting baseline emissions for the ZILMP**.

The program covers an area of 3.87 million ha, including 1.98 million ha of forest in 2013. In the past, forest inventories were already conducted in the area - especially within forest concessions - but they were all related to forest production and assessed the volumes of commercial wood only. We found only one forest inventory - conducted by Thomas Prin (Prin 2008) in the Gilé National Reserve (GNR) – that entailed comprehensive biomass assessment and whose raw data were available.

The *International Institute for Environment and Development* (IIED) also carried out a forest inventory to assess carbon stocks in Sofala and Zambézia Province in 2015, as part of the TREDD project. Some plots were inventoried within the ZILMP area in the Ilé district, but we were not able to access the data.

Prin's results led to the description of 4 strata of the Miombo forest. However, because it was based on species composition rather than on carbon stocks, this stratification could not be used for the establishment of the REL. Starting from this study, we were able to assess carbon stocks using a database of trees' diameters and an appraisal of the density of the various wood species: carbon stocks were estimated at 36.6 tC/ha (with a standard deviation of 13.3 tC/ha). However, Prin's study was not designed for biomass estimation and his dataset could not be used to establish a REL for an Emission Reductions (ER) program for several reasons: (i) it only took into account the GNR's forest cover; (ii) it was based on few plots (n=39) and (iii) its inventory was conducted several years ago.

Consequently, we conducted another inventory to evaluate carbon stocks in tree biomass in the program area. Its methodology and the analysis of its results to establish a REL are detailed in this present report. In order to be representative, the inventory was conducted in several forest massifs in the program area - in the core GNR, in its buffer zone and in other massifs throughout the ZILMP area. The inventory work was separated in 2 periods because the validity of some results was questioned after the 1st phase. These periods are separated by only few months which is not prejudicial for the quality of the results. Finally, a total of 100 plots were sampled which is considered sufficient to be representative according to the Winrock tool for biomass inventory size (Walker, Pearson, and Brown 2007).

1. Methodology for the assessment of carbon stocks

1.1. Pre-stratification

Two main types of forest exist in the program area: Miombo tropical dry forest and mangroves.

Mangroves are known to be homogeneous since they are composed of few species and are located in a specific landscape (low and water land). Hence no further stratification has to be done. However, according to the low deforestation rates in this type of forest, it will probably not be significant in terms of emissions comparing to emissions from Miombo forest (see Reference emission level and baseline for mangroves).

In his study, Prin divided the GNR forest into 4 strata. However, this stratification was not based on carbon stocks variations but on arbitrary floristic considerations: it was not retained in our study. Even if the Miombo forest shows structural variations (tree height and density), it was not possible to establish prior thresholds values for the inventory. Our field observations within the whole ZILMP area found that the Miombo forest is quite homogenous within the zone: it does not require pre-stratification.

1.2. Carbon pool selection

Carbon pools that were included or excluded from the analysis are the following:

- We analyzed the distribution of carbon stocks among different pools in the literature. While trees' **aboveground biomass** (AGB) is always significant (>70%), non-tree AGB is insignificant in forest classes but significant in non-forest classes. Non-tree AGB was taken into consideration only in post-deforestation classes. Such a method is conservative as it reduces the emission factor of conversion from forest classes to post-deforestation ones. Post deforestation carbon stocks were estimated from literature data.
- **Belowground biomass** (BGB) was taken into consideration for both forest and post-deforestation classes as it usually accounts for 15% to 30% of AGB. BGB was estimated thanks to default value of root to shoot ratio from IPCC (IPCC 2006).
- Thanks to field observations, we considered that lying **deadwood** was not a significant pool as communities usually collected it for firewood. As this pool is not considered to increase in post-deforestation classes, it was excluded. Standing deadwood was also considered as not significant according to field observations.
- As there are several logging concessions within the program area and also high level of illegal logging outside concessions, the **harvested wood product** was estimated within the calculation of degradation from logging baseline.
- **Litter pool** was excluded, as it is usually not significant.

- **Soil organic carbon** (SOC) can be significant, with similar amount of carbon compared to the above ground biomass, so a specific section (see 2.3) in the present analysis will analyze whether to include it.

The following table summarizes pools that were included within or excluded from project boundary.

Table 15: Carbon pools included within or excluded from program boundary

Carbon pools	Included / TBD*/ Excluded	Justification / Explanation of choice
Aboveground	Tree: **Included**	▪ Carbon stock changes in this pool are always significant.
	Non-tree: ▪ **Included in post deforestation classes** ▪ **Not included in forest classes**	▪ This carbon pool is included in post-deforestation classes as crops (peanut, cassava, maize, etc.) and fallows; those are included in the replacement land-cover in the baseline scenario. Literature data were used for this pool. ▪ This carbon pool is excluded in forest classes, as it is usually not significant. ▪ It is conservative to take it into consideration only in post-deforestation classes.
Belowground	**Included**	▪ BGB of trees is recommended, as it usually represents between 15% and 30% of AGB.
Dead wood	**Not included**	▪ Lying dead wood was not included in forest classes based on field observations. Indeed, this wood is usually collected for firewood so it does not represent a significant pool. ▪ Standing deadwood has not been included as it does not seem to be significant and it is conservative not to include it.
Harvested wood products	**Included**	▪ As there are several concessions within the program area and high level of illegal forest exploitation, this pool was estimated in the degradation from logging baseline. The program still has to decide whether this activity should be included in the REL.
Litter	**Not included**	▪ Does not have to be included.
Soil organic carbon	**To be assessed**	▪ Carbon stock and stock changes for this pool can be significant.

1.3. Forest inventory

According to carbon pools considered, field inventories have to be carried out for aboveground biomass in forest.

1.3.1. Analysis of sample size

Winrock developed a tool[2] (Walker, Pearson, and Brown 2007) to calculate the number of plots to be inventoried in order to respect accuracy requirement of the Clean Development Mechanism (CDM) methodologies. It depends on the mean biomass measured and on the standard deviation.

With our current dataset, to achieve a confidence level of 90% with an error of 10%, 50 plots should be inventoried. With the current inventory, the sample size (100) is largely above this minimum threshold guaranteeing the accuracy and representativeness of the inventory.

1.3.2. Sampling strategy

For them to be representative, inventories were planned in several parts of miombo forests of the program area: forest in the GNR core zone, forest in its buffer zone, forest in the Mocubela – Mulevala massifs, forest in the Alto-Molocué and North of Gilé districts... A total of 100 plots were inventoried (see Figure 12).

A sample design was realized with groups of 4 plots on a topographical and vegetation transect in order (i) to establish a correlation between biomass stocks estimations and biophysical variables, such as vegetation indexes, slope or elevation – for biomass mapping purposes and (ii) to reduce inventory work time.

[2] http://www.winrock.org/resources/winrock-sample-plot-calculator

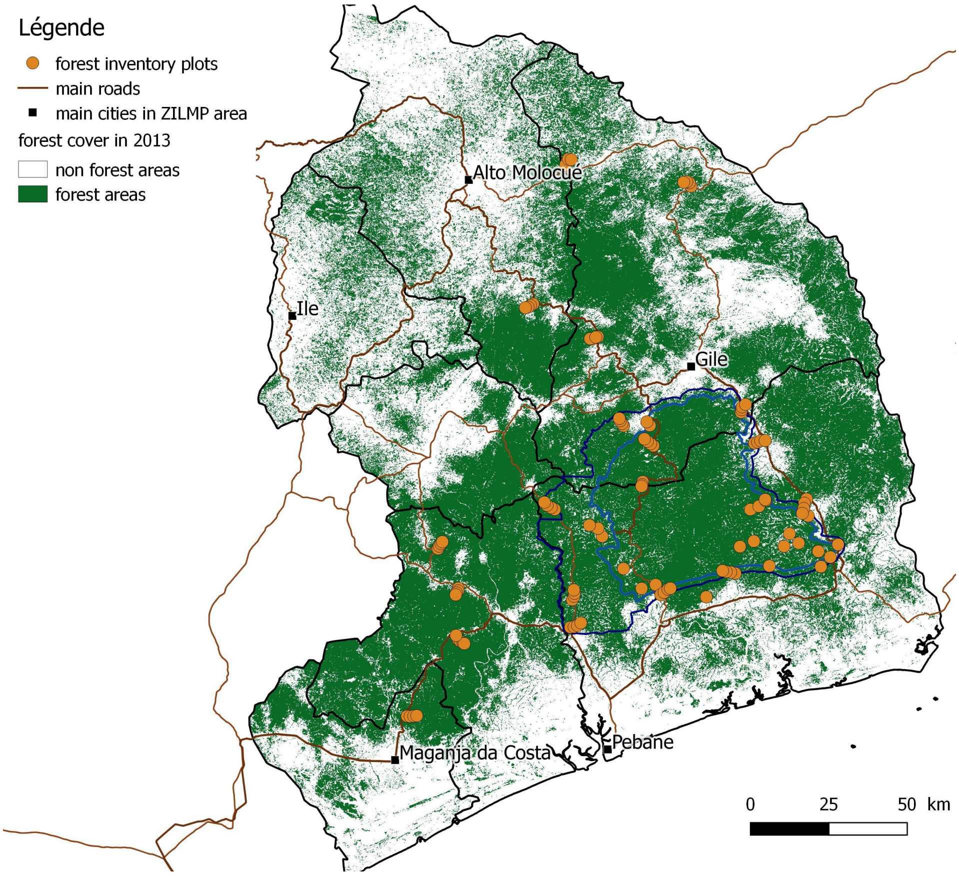


Figure 12: Location of plots realized in Miombo forests of the program area

1.3.3. Plot design

The inventory was conducted on circular plots of 16 m of radius. For each plot, GPS coordinates and altitude were collected. For every trees above 5 cm diameter, the following measurements were gathered: diameter at breast height (DBH), height (with a vertex) and tree species.

Figure 13: Height measurement and species identification (on the left) and typical Miombo forest (on the right)

1.3.4. Post stratification

At this stage of the study, no post stratification was established. The relevance of such an analysis still needs to be evaluated.

1.4. Carbon stocks in forest and uncertainties

1.4.1. Selection of an allometric equation

Aboveground biomass is calculated using an allometric equation linking biomass to diameter and, potentially, height. Given the high species composition heterogeneity in tropical forests, multi-species equations are more relevant. Few generic equations are available for the Miombo forest (see Annex 3: Choice of an allometric equation, for their presentation and rationale for the choice). We chose the Chave's global equation (Chave et al. 2014) presented below.

Chave's allometric equation used:

Equation 4

$$AGB = 0.0673 \times (\rho D^2 H)^{0.976}$$

Where AGB is aboveground biomass, ρ is wood density, H is tree height and D is diameter at breast height.

Trees height and diameter are measured during inventories. Wood density for each species encountered during inventories was selected from the global wood density database (Zanne et al. 2009; Chave et al. 2009).

1.4.2. Root-to-shoot ratio

According to IPCC (2003), carbon fraction in aboveground biomass averages 0.47 tC/tdm. In IPCC (2006), belowground to aboveground ratio (or root-to-shoot ratio) in tropical dry forests is expected to average:

- 0.56 if aboveground biomass is below 20 t/ha.
- 0.28 if aboveground biomass is above 20 t/ha.

2. Carbon stocks and emission factors

2.1. Miombo forests

2.1.1. Results from inventories in the Miombo forest

Results of the inventory regarding carbon stocks and the main species encountered are presented in the following tables.

Mean total biomass in Miombo forest is 84.7 tC/ha or 310.7 tCO_2eq/ha (Table 16). The results of 90% confidence interval (90% CI) give a **relative margin of error**[3] **of 7%** for the overall accuracy, which respects the FCPF-MF for carbon stocks estimation (FCPF 2013).

Table 16: Carbon stocks in the natural Miombo forest in the ZILMP area to recent biomass inventory (n=100 plots)

	Aboveground	Belowground	Total
	Carbon stocks in tC/ha		
Average	66.1	18.7	84.7
Standard deviation	28.4	7.7	36.1
90% CI	4.7	1.3	5.9
	Carbon stocks in tCO_2eq/ha		
Average	242.3	68.4	310.7
Standard deviation	104.0	28.4	132.3
90% CI	17.1	4.7	21.8

Most widespread species are used by local communities for firewood or charcoal production. The majority of them belong to Fabaceae family (N-fixing species - Table 17): they can also be used to maintain or improve soil fertility with nitrogen.

Table 17: Main species encountered during the inventory in natural Miombo forest

Scientific name	Local name	Family	Frequency in the ZILMP
Brachystegia boehmii	Mutxacatxa	Fabaceae	10%

[3] This value corresponds to the 90% CI divided by the biomass mean

Julbernardia globiflora	Nampacala	Fabaceae	7%
Diplorhynchus condylocarpon	Txocori	Fabaceae	7%
Brachystegia spiciformis	Murotxo	Apocynaceae	6%
Pterocarpus angolensis	Mpila	Fabaceae	4%
Annona senegalensis	Muiepe	Fabaceae	4%
Dalbergia nitudila	Evico	Annonaceae	4%
Pseudolachnostylis maprouneifolia	Mutolo	Fabaceae	3%
Erythoropheum africanum	Mucarara	Phyllanthaceae	3%
Combretum zeyheri	Mopacalawa	Fabaceae	3%

2.1.2. Carbon stocks in biomass of post deforestation lands

Several inventories were conducted in Mozambique to estimate carbon stocks in different land use and land cover classes (Ryan et al. 2010; Williams et al. 2008). Even though they made estimates in savannah, none of those inventories has directly measured post deforestation carbon stocks, nor did they evaluate non-woody biomass. Another report assessed aboveground biomass density in savannahs and crops (McNicol et al., 2011). By applying a root shoot ratio value (0.56 from IPCC (2006) – see previous section), we were able to deduce post-deforestation carbon stocks. We suggest taking into consideration the average stock in savannahs and crops (Table 18), which is subtracted to measured carbon stocks in forest, in order to produce emissions factors that will be considered to define the REL. Results are presented in the following table.

Table 18: Estimation of carbon stocks in savannahs and crops for post-deforestation classes and resulting emission factors (in tCO_2eq)

	Carbon stocks in tC/ha		
	Above ground (from McNicol et al., 2011)	**Estimation of below ground with root-to-shoot ratio**	**Total**
Savannah	11.5	6.4	17.9
Crops	9.4	5.3	14.7
Average	**10.45**	**5.9**	**16.3**
	Emission factors in tCO_2eq/ha		
	Aboveground	**Belowground**	**Total**
	203.9	**46.7**	**250.8**

2.2. Mangroves

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 as well as in soil (Table 19). Carbon in soil represents the main pool, as expected for this ecosystem. In addition, carbon stocks in mangrove biomass are higher than those in the Miombo forest (Table 16).

No post deforestation evaluation of stocks were found in literature but Siikamäki (2012) evaluate losses from biomass and for soil carbon after deforestation to be, respectively, 75% and between 30% and 90%.

Table 19: Summary of carbon stocks density (tC/ha) in mangroves of the Zambezi delta (from Stringer et al. 2015)

	Carbon stocks density in tC/ha										
	Global mean	Strata 1		Strata 2		Strata 3		Strata 4		Strata 5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aboveground living biomass in tC/ha	**140.82**	55.4	11.8	96.7	16.4	127.4	20.2	183	20.6	241	36.2
Belowground tree biomass in tC/ha	**43.4**	18.9	3.8	31.7	5	40.4	5.9	56.3	5.5	69.7	9.4
Carbon density in soil (0-200 cm) in tC/ha	**284.26**	278.76		285.72		299.79		276		281	
Total carbon stocks	**468.48**	**353.06**		**414.12**		**467.59**		**516**		**592**	

2.3. Soils

No specific inventories for soils were made for the present study but data are available in the literature to evaluate if the soil carbon is a significant pool to be included in the baseline:

- Woollen et al. (2012) sampled soil carbon stocks in the Miombo forest in Mozambique (in the Gorongosa National Park – soils range from sandy and ferralytic to more hydromorphic, which is comparable to the global situation of the ZILMP area) and found an average of 12.1 tC/ha (± 0.6 tC/ha) in the top 5 cm and 40.1 tC/ha (± 2.5 tC/ha) in the top 30 cm.
- Ryan et al. (2010) found that, between 0 and 50 cm, the average carbon stock in soil was 76.3 tC/ha in Sofala Province.
- Williams et al. (2008) also conducted a soil carbon stocks analysis in forests and in post deforestation areas such as abandoned *machambas* (from 2 to 20 years) in Mozambique (Sofala Province). He unexpectedly concluded that post deforestation dynamic was flat: there was no progressive decrease in soil carbon after fields' abandonment. However, he underlined a clear decrease of soil carbon between forests (but no average is available from his results for the Miombo forest – median was 57.9 tC/ha) and abandoned fields. According to his results, the average for post deforestation soil carbon is 45.2 tC/ha (± 14.1 tC/ha).
- Etc Terra realized an inventory around the GNR for the development of the Gilé REDD+ project. Although it still has to be completed, this inventory is interesting because it is situated in Zambézia province. The results show very low carbon stocks in soil organic matter: 14.3 tC/ha (± 9.2 tC/ha) for the Miombo forest and 9.2 tC/ha (± 16.5 tC/ha) for post-deforestation lands, resulting in a difference of 5.1 tC/ha or 18.7 tCO_2eq/ha.

It is not possible to establish emission factors with those estimations as they all use different methods in various locations in Mozambique. However, it appears that carbon stocks in the Miombo forest are relatively low and that the difference with soil carbon stocks in post-deforestation lands is also small. According to FCPF Methodological framework (criterion 4.2), a pool must be included if it contribute to 10% of the global emissions. As activity data are the same for carbon stocks changes in biomass and in soils, the criterion can be interpreted as 10% of emissions factor: emission factor for soil should be above 23.7 tCO_2eq/ha, which is unlikely according to results in literature – that show low difference between forest and post deforestation areas. **Hence we recommend, as a conservative choice, not including the soil pool in the baseline.**

3. Emissions baseline

3.1. Historical trends

According to results from the analysis of historical deforestation, annual deforestation area increased over the 2000-2013 period (Table 20 and Figure 14). However, following the FCPF methodological framework (FCPF 2013), the baseline has to be equal to the mean historical emissions (criterion 13.1), over a reference period of 10 years (criterion 11.2). Here the 2005 – 2013 period was selected (Table 20).

Table 20: Annual deforestation (in ha/year) in each district of the program area on several periods from 1990 to 2013

	Annual deforestation on several study periods (in ha)				Global average	**Average for the reference period**
	1990-2000	2000-2005	2005-2010	2010-2013	1990-2013	**2005-2013**
Alto-Molocué	3,959	2,306	2,858	5,377	3,533	4,106
Gilé	3,312	2,140	3,739	5,269	3,414	4,420
Ilé	1,127	469	1,330	2,097	1,129	1,766
Maganja da Costa	931	916	273	320	708	296
Mocubela	704	1,986	1,107	586	1,037	875
Mulevala	261	302	753	1,128	504	930
Pebane	2,758	3,255	2,361	2,462	2,740	2,405
ZILMP area	**13,051**	**11,375**	**12,420**	**17,238**	**13,064**	**14,798**
Gilé National Reserve	*9*	*61*	*15*	*23*	*24*	*19*
GNR buffer zone	*112*	*237*	*332*	*326*	*216*	*329*
GNR + buffer zone	*122*	*290*	*352*	*349*	*240*	*351*
Mangroves	*1*	*-*	*0.8*	*0.2*	*0.5*	*0.5*

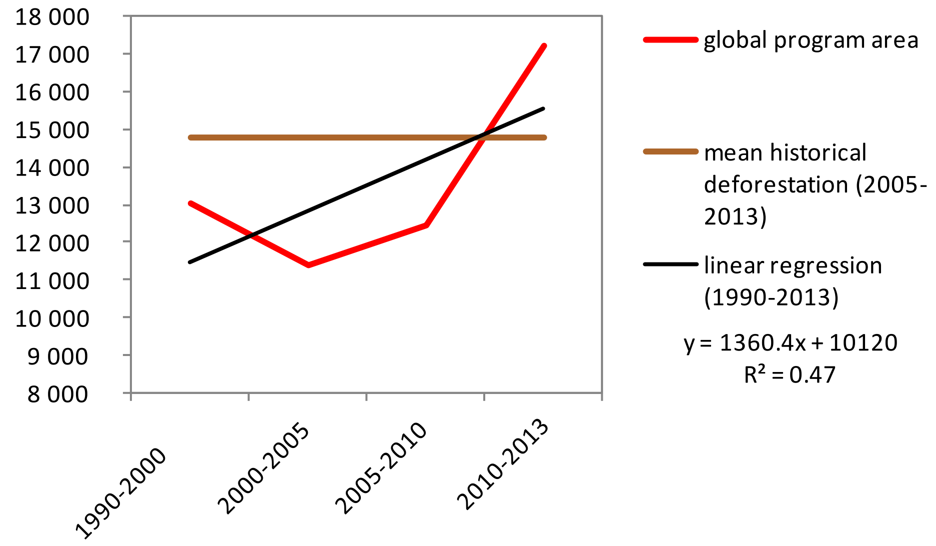


Figure 14: Evolution of the annual deforestation areas (in ha/year) for the program area over several historical periods and mean historical deforestation on the reference period (From the analysis of historical deforestation – Etc Terra)

3.2. Reference emission level and baseline for the Miombo forest

Projected emissions over a period of 10 years (2014-2024) were then calculated on the basis of the average annual level of emissions, calculated with estimations of annual deforestation area and emissions factors for the Miombo forest (Table 18). In the deforestation process, aboveground carbon stocks is immediately emitted during the process of "cutting and burning" – the main land transition being "slash and burn" agriculture. However, belowground biomass is progressively degraded. According to IPCC recommendations, a level of emission of 10%/year was selected. Baseline is presented in the following table (Table 21). **The annual emission level for the baseline is 3.3 $MtCO_2eq$/year**.

***A priori*, the ZILMP program does not fulfill criterion 13.2 of the FCPF MF** (low historical deforestation with high forest cover, or clear justifications for the projected increase of deforestation in the future) providing for an adjustment of the level of emissions in the baseline. However, the analysis of historical deforestation shows that the annual areas of deforestation continue their upward trend (Figure 14), which is probably linked to demography (see report on the causes of deforestation). As a consequence, it could be relevant for the program to make provision for such adjustment. According to FCPF methodological framework, maximum adjustment is 0.1% of total carbon stocks (criterion 13.4). With current data, the total carbon stocks of the Miombo forest in the program area (above and belowground biomass) are 616 $MtCO_2eq$. **This would lead to a maximum adjustment of 0.61 $MtCO_2eq$/year, raising the level of emissions for the baseline to 3.95 $MtCO_2eq$/year.**

Table 21: Summary of baseline emissions of the program with a projection of mean emissions for the 2005-2013 period

Periods		Mean historical (2005-2013) deforestation area - ha	Emissions due to deforestation		
			Emissions related to aboveground biomass - tCO_2eq	Emissions related to belowground biomass - tCO_2eq	Total baseline program emissions - tCO_2eq
Historical reference period	2005	12,420	2,532,793	58,041	2,590,833
	2006	12,420	2,532,793	116,082	2,648,874
	2007	12,420	2,532,793	174,123	2,706,915
	2008	12,420	2,532,793	232,164	2,764,956
	2009	12,420	2,532,793	290,205	2,822,997
	2010	17,238	3,515,182	483,319	3,998,501
	2011	17,238	3,515,182	563,872	4,079,054
	2012	17,238	3,515,182	644,425	4,159,607
	2013	17,238	3,515,182	724,978	4,240,160
Baseline period	2014	14,798			**3,334,655**
	2015	14,798			**3,334,655**
	2016	14,798			**3,334,655**
	2017	14,798			**3,334,655**
	2018	14,798			**3,334,655**
	2019	14,798			**3,334,655**
	2020	14,798			**3,334,655**
	2021	14,798			**3,334,655**
	2022	14,798			**3,334,655**
	2023	14,798			**3,334,655**
	2024	14,798			**3,334,655**

3.3. Reference emission level and baseline for mangroves

Following the same method as the one used for the Miombo forest (see previous section), we conducted an assessment of baseline emissions for mangroves in the program area. For carbon in soil, we used the conservative 30% loss estimation.

Because of the low deforestation areas (less than 1 ha per year - see Table 20), the emissions due to deforestation in mangroves are low. **The estimation of annual emissions for the baseline is 293 tCO_2eq**, which is less than 1% of global emissions from the Miombo forest.

As a conclusion, deforestation in this stratum is not a significant source of emission: in conformity with criterion 4.2 of the FCPF MF, we suggest not to include it into the ER REL of the program.

3.4. Reference emission level and baseline for degradation

Emissions due to degradation were estimated for charcoal production as well as for legal and illegal logging. They are detailed in the relevant paragraphs within the section related to the drivers of deforestation:

- **Emissions due to charcoal production** were calculated through the assessment of annual consumption in each urban center and the impacted areas and based on producers' average practices when building a kiln. Calculation of emissions factors is detailed in Annex 5.
    - Given the limited data available in literature, carbon stocks of post-deforestation land uses were not assessed. However, a study focusing on regeneration biomass after "slash and burn" agricultural practice or charcoal production will be conducted around the GNR, in order to complete our analysis.
    - According to the default factors selected to produce emission factors, estimations vary between 0.3 and 0.8 $MtCO_2eq/yr$. They will have to be refined if the program baseline is to take into account emissions from degradation (Figure 62). However, since the most conservative option for defaults factors seems unlikely, charcoal production may account for more than 10% of total emissions.
- **Emissions due to forest exploitation** were estimated with data relating to the total volume that is officially exploited in the program area and to the estimated share of illegal logging.
    - Great uncertainties exist about those volumes: a field survey would be necessary to improve the analysis, if degradation is to be taken into account in the program baseline. It will however remain difficult to access data on illegal logging.
    - It was impossible to gather data on the roads created for wood extraction out of the logging area. Hence, some emissions are not part of this estimation, which is therefore conservative. Furthermore, since there are no available estimates on the areas impacted by roads or wood parks for the Zambézia province, activity data could not be established.

Results are summarized in the following table. According to the FCPF MF (criterion 3.3), if degradation accounts for more than 10% of global emissions, it has to be included in the program baseline. **It is therefore recommended to perform additional studies to refine the estimation of degradation emissions.**

Those studies would enable the definition of expansion factors that would be adapted to the program context, in order to (i) assess biomass used for charcoal production, (ii) refine activity data for charcoal production through additional survey on the proportion of charcoal produced in the fields, (iii) analyze regeneration after charcoal production (already planned for the GNR REDD+ project) and (iv) produce data on roads construction for forest exploitation (legal and illegal).

For the ER-PD, a monitoring system should be based on regular surveys regarding specific aspect of degradation. Those surveys would include a monitoring of the number of charcoal producers, the size of kilns and the location of production – either in natural forest or in fields, in association with agriculture - the volumes exploited by legal and illegal logging and the creation of skid roads or trails.

Table 22: Results on emissions due to different degradation drivers for the ER program baseline

Causes of degradation	Estimation of mean annual areas impacted - in ha	Conservative hypothesis for charcoal		Non conservative hypothesis for charcoal	
		Estimation of mean emissions - in tCO2eq/yr	Contributions of causes to total emissions	Estimation of mean emissions - in tCO2eq/yr	Contributions of causes to total emissions
Charcoal production	10,770	288,537	8.0%	804,120	19.4%
Legal and illegal logging		37,945	1.1%	37,945	1.1%

4. Above ground carbon density mapping

Carbon density mapping enables to provide information on carbon stocks and their spatial distribution. It can help to identify priority areas for program implementation and can be used as a reference for MRV. This modeling exercise - with the aim of predicting AGB value - is based on field carbon stocks data from forest inventories (see section 1.3) correlated with spatially-explicit biophysical factors (relief, vegetation cover, soil, hydrography, etc.), in order to explain spatial variations of forest biomass. The proposed approach provides an estimation of carbon stocks per land unit represented by a pixel (here, a 30-meters side square).

4.1. Methodology

Factor maps based on biophysical information (relief, vegetation cover, soil, hydrography, etc.) were used as input datasets and the model is calibrated on carbon stocks data derived from our forest inventory. The model uses regression analysis and the *RandomForest* algorithm (Breiman 2001), which is available on the *R* software. This algorithm is a nonlinear model based on the principle of decision trees (Breiman 2001) that enables to test and select the most reliable and robust combination of factors to predict AGB in comparison with observation data from inventory plots. It was successfully used to solve classification problems (e.g., land cover and land cover change mapping) or regression problems (e.g. carbon stock mapping). Most recent examples include the pan-tropical biomass map from Baccini et al (2012) and the national AGB map of Peru (Asner et al, 2014). This algorithm offers many advantages such as integration of correlated variables that may be either quantitative or qualitative, automatic selection of the discriminant factors, little tuning and low bias in output prediction (Breiman, 2001).

AGB value of the forest inventory plots were correlated with the underlying pixels values of the factor maps. Forest inventory plots are circular with a 32-meters diameter and factor maps resolution was standardized to a 30 grid resolution. In order to extract environmental values on the point forest sample, a 30-meters buffer was drawn around each plot center. For the modeling, we selected 70% of the entire dataset for model calibration and 30% for accuracy measurements. The methodology follows three main steps, which are detailed below.

4.1.1. Preparation of the field sample AGB values

Among 117 forest inventory plots, 82 were used to calibrate the model (corresponding to 296 pixels on the factor map) and 35 to validate the map (corresponding to 126 pixels on the factors map or on the final biomass map). In addition, data from non-forest areas (savannah lands, cultures, bare soil, etc.) are necessary to calibrate low AGB values. In this study, we added several plots that ought to have null biomass values – that is, rocks (e.g. inselberg) and water bodies. We excluded bare soils observations since it was difficult to ascertain that the point location would be completely "bare" in the Landsat images used. The final point sample dataset is presented in the figure below.

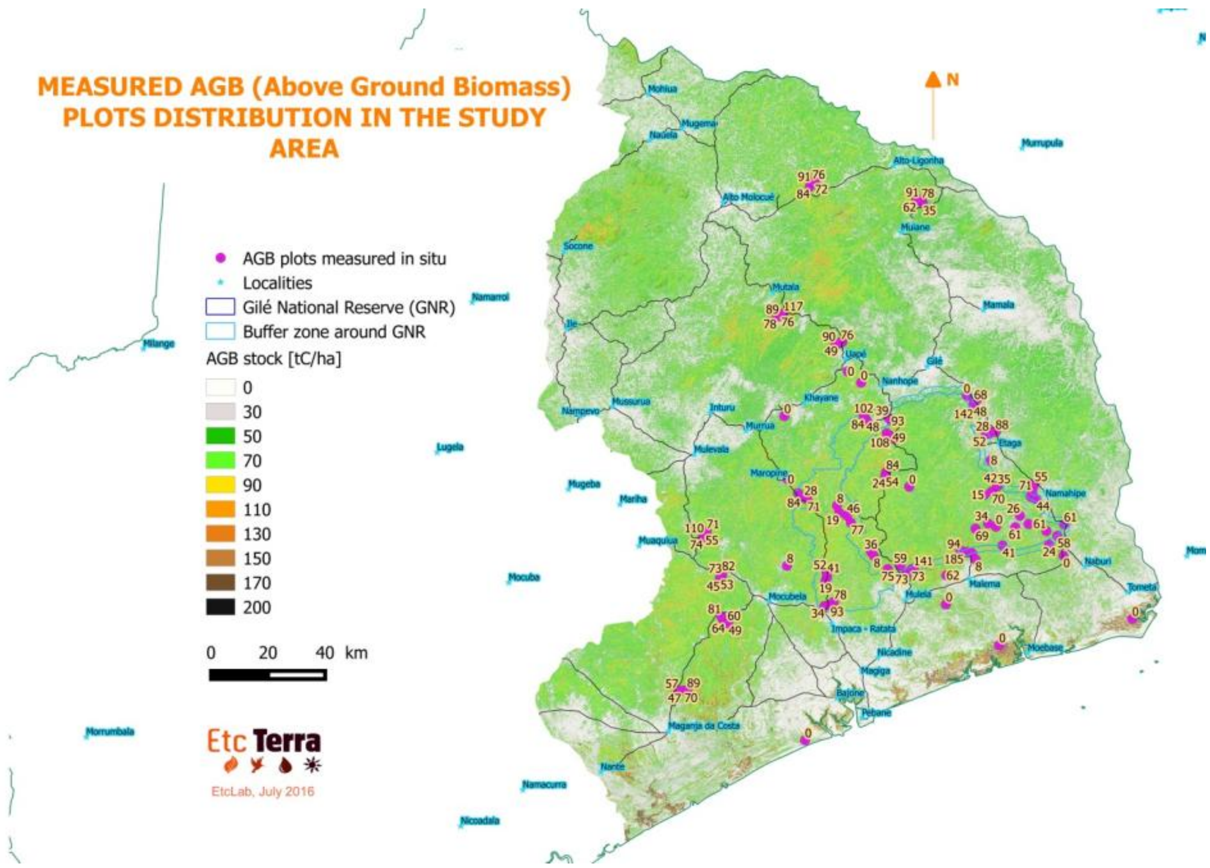


Figure 15: Field plots used in the model for AGB mapping

4.1.2. Preparation of the biomass factors maps;

Biophysical data used as inputs in the model are presented and explained in the following table and figure. Data are distributed according the following variables:

- **Topography:** micro-variations of elevation, slope, orientation and slope convexity are known to influence biomass through forest density and trees' size.
- **Soil and vegetation:** vegetation indices derived from satellites images reflect vegetation density and are usually well correlated with ABG biomass. Additionally, near and middle infra-red satellite bands are known to reflect soil conditions, especially when soil is not entirely covered with vegetation.
- **Hydrology:** riparian forests present slightly different carbon stocks and their location can be mapped thanks to the hydrographic system of the area (flow area, wetness index).

Finally, biophysical spatial datasets were collected from different sources (Table 23) and preprocessed in order to get the same geometrical properties.

On each map, values of the pixels corresponding to the forest field plots were extracted in order to establish regressions in the model. As previously explained, several pixels on factor maps correspond to a field observation plot. Thus, on each factor map (11 factor maps are used), 225 pixel values were extracted for calibration and 96 for accuracy assessment.

Table 23 : List of the biomass factors calculated and tested

ID	Name	ID	Biomass factor represented		Source
			Category	**Description**	
1	Relative height	**RH**	Topography	Instead of directly using the elevation, using relative height factor is a mean to show more detectable variability in the study area.	DEM, SRTM, v4
2	Slope	**SLP**		Slope intensity may be a constraint for cultivation and selected logging.	
3	Aspect	**ASP**		It gives the slope orientation direction.	
3	Profile curvature	**P_curv**		Profile curvature is the curvature intersecting with the plane defined by the Z axis and maximum gradient direction. Positive values characterize convex profile curvature, negative values characterize concave profile.	
4	Plan curvature	**L_curv**		Plan or Longitudinal curvature is the profile curvature intersecting with the plane defined by the surface normal and maximum gradient direction.	
5	Vegetation Cover Fraction	**VCF**	Soil and vegetation	Percentage of vegetation cover of the study area in 2000	VCF Hansen 2000
6	Principal Components 1	**PC1**		First band of the Principal Compound Analysis (PCA) using the L8 raster bands	L8 mosaic 2013
7	Principal Components 2	**PC2**		Second band of the Principal Compound Analysis (PCA) using the L8 raster bands	
8	Transformed Vegetation Index	**TVI**		Normalized difference between near infrared and red bands to derive vegetation properties in that region	
9	Near Infrared index	**NIRI**		Normalized difference between shortwave infrared and near infrared bands	
10	Flow accumulation	**FA**	Hydrology	Accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster.	DEM, SRTM, v4
11	Topographic Wetness Index	**TWI**		Wetness index derived directly from topographic parameters	

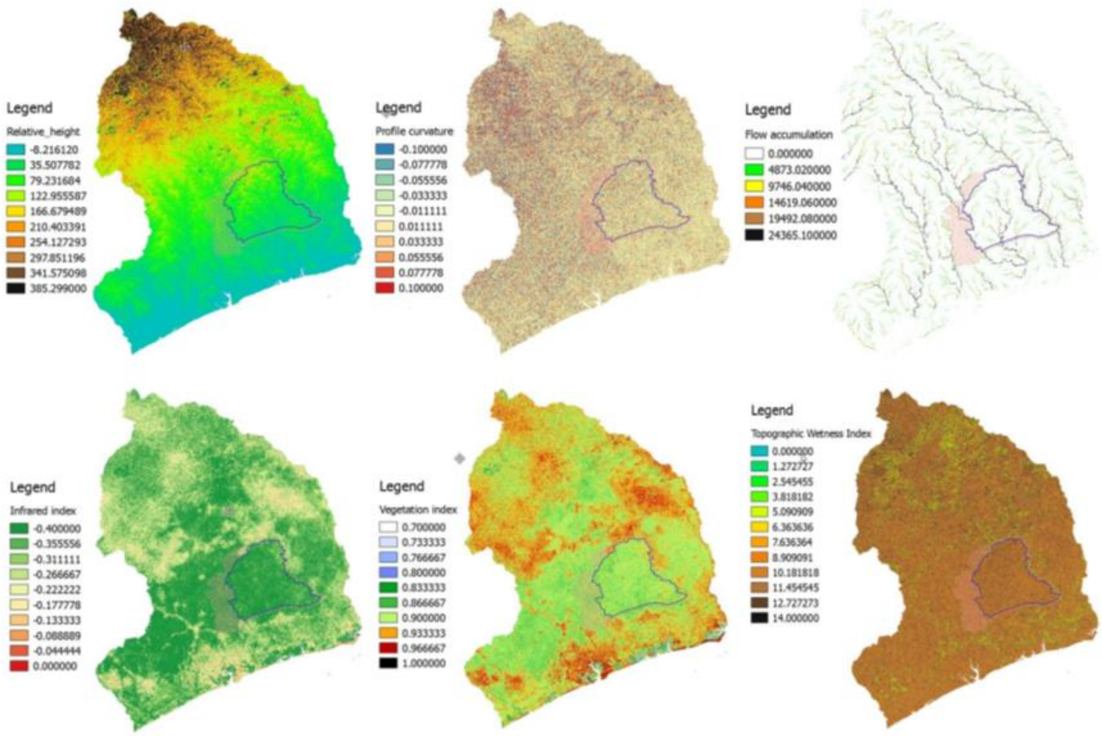


Figure 16: Illustration of some biomass factor maps (from top left to bottom right: relative height, profile curvature, flow accumulation, infrared index, transformed vegetation index, topographic wetness index)

4.1.3. Selection of the most accurate carbon density map

Several combinations of factors were tested to build the most robust model with the *RandomForest* algorithm (Table 24). Model validation was possible through comparing (i) the carbon stocks of predicted values by the regression models with the selected combination of factors with (ii) those measured on the validation sites. Selection of the most robust model was based on the following indicators for accuracy assessment:

- **Coefficient of determination (R^2),** which expresses the correlation between predicted AGB carbon stocks and measured ones. R^2 value range from 0 (no correlation) to 1 (perfect correlation).
- **Root Mean Square Error (RMSE),** which expresses the average error of the model in tons of carbon per hectare. The lower is the RMSE value, the better is the precision of the model. RMSE could also be expressed as the relative to the mean (RMSE/average biomass stock) in percentage.

Table 24 : List of the combination of factors tested to select the most robust model. See table 1 for the complete description of the factor.

Test	Factor combination	Quality indices		
		R2	RMSE (MgC/ha)	Bias (MgC/ha)
1	VCF2000 + NDVI_2000 + NIRI_2000 + Mosaic_hansen_2000 + ALT+ PEN + RUG	0.55	23.03	
2	NDVI_hansen2013 + NIRI_hansen2013 + Mosaic_hansen_2013 + Hauteur_relative_srtm + Convexité_ver + Convexité_hor + TWI	0.25	29	
3	TVI_hansen2013 + NIRI_hansen2013 + CP1_Mosaic_hansen_2013 + C P2_Mosaic_hansen_2013 + Hauteur_relative_srtm + TWI+Conv_h + Conv_v+ASP + PEN + Flow_acc_srtm	0.52	21.84	4.54
4	TVI_hansen2013 + NIRI_hansen2013 + CP1_Mosaic_hansen_2013 + C P2_Mosaic_hansen_2013 + Hauteur_relative_srtm + TWI+Conv_h + Conv_v+ASP + Flow_acc_srtm	0.53	21.35	4.36

After several tests in the sets of environmental factors, based on model quality indicators, the following model was retained (model 3, Table 24):

Equation 5

AGB carbon stocks = f (NIRI+ TVI+ PC1+PC2+RH+P_curv+L_curv+ASP+TWI+FA+SLP)

The successful and retained model shows acceptable results in terms of quality indicators: R^2 coefficient of 0.52 and an RMSE of 21.8 tC/ha. This corresponds to a 36% uncertainty (relative RMSE to the regional mean) at pixel level. This average level of accuracy at pixel scale is common for regional biomass mapping application, which may range from 20 to 60% according to the height of the trees (Asner et al, 2014). Accuracy is improved by aggregating the pixels values onto wider areas (larger pixel) or within forest stratum map.

4.2. Results: carbon density map and accuracy assessment

As previously mentioned, model 3 has been retained as it presents the best results regarding to the map that was produced and quality indicator. The following figure represents correlation between observed AGB and predicted AGB by the model.

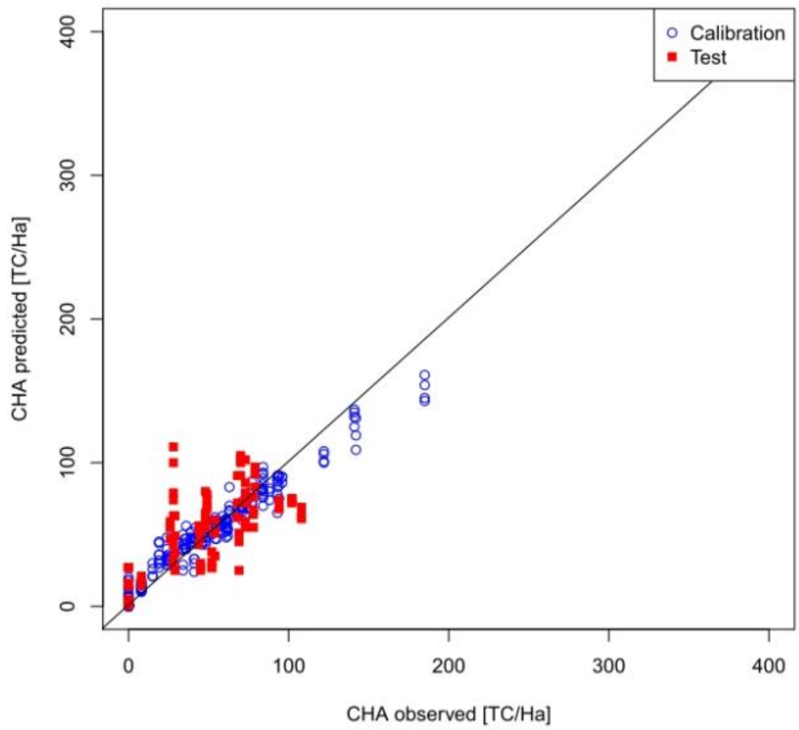


Figure 17: Correlation predicted and observed AGB data on location of forest inventory plots

The AGB map that was produced with the selected model is presented in the following figure. According to the map, mean Miombo forest AGB carbon stocks in the ZILMP area is 59.8 tC/ha (Table 25), comparable to the 66.1 tC/ha calculated with field forest inventories (see section: Results from inventories in the Miombo forest). Maximum carbon stocks are found in specific forested land covers: riparian forests, plantations (*e.g.* Socone) and mangrove forests. Some patches of high carbon stocks are also found in Miombo forests (Figure 12). The most forested districts are those with the highest mean carbon stocks (all land cover considered – see Table 25). According to the map, post-deforestation carbon stocks (carbon stocks in non-forest areas) are 21.5 tC/ha (Table 25), which is in this case higher than the value that was selected in the bibliography (10.5 tC/ha - see section: Carbon stocks in biomass of post deforestation lands).

Table 25: AGB summary statistics for different districts of the ZILMP area

	AGB carbon stocks in tC/ha				
	ZILMP total area			Forest areas	Non-forest areas
Districts	**average**	**stdv**	**max**	**average**	**average**
Alto Molocue	45.1	17.2	139	62.3	25.4
Gile	44.3	18.9	152	54.3	18.9
Ile	40.9	16.8	152	59.8	25.4
Maganja da Costa	50.3	31.2	157	65.5	25.0
Mocubela	52.8	26.2	165	63.4	18.6
Mulevala	42.1	19.4	152	56.6	21.2
Pebane	48.0	26.6	164	56.6	16.2
Average	**46.2**	**22.3**	**154.4**	**59.8**	**21.5**

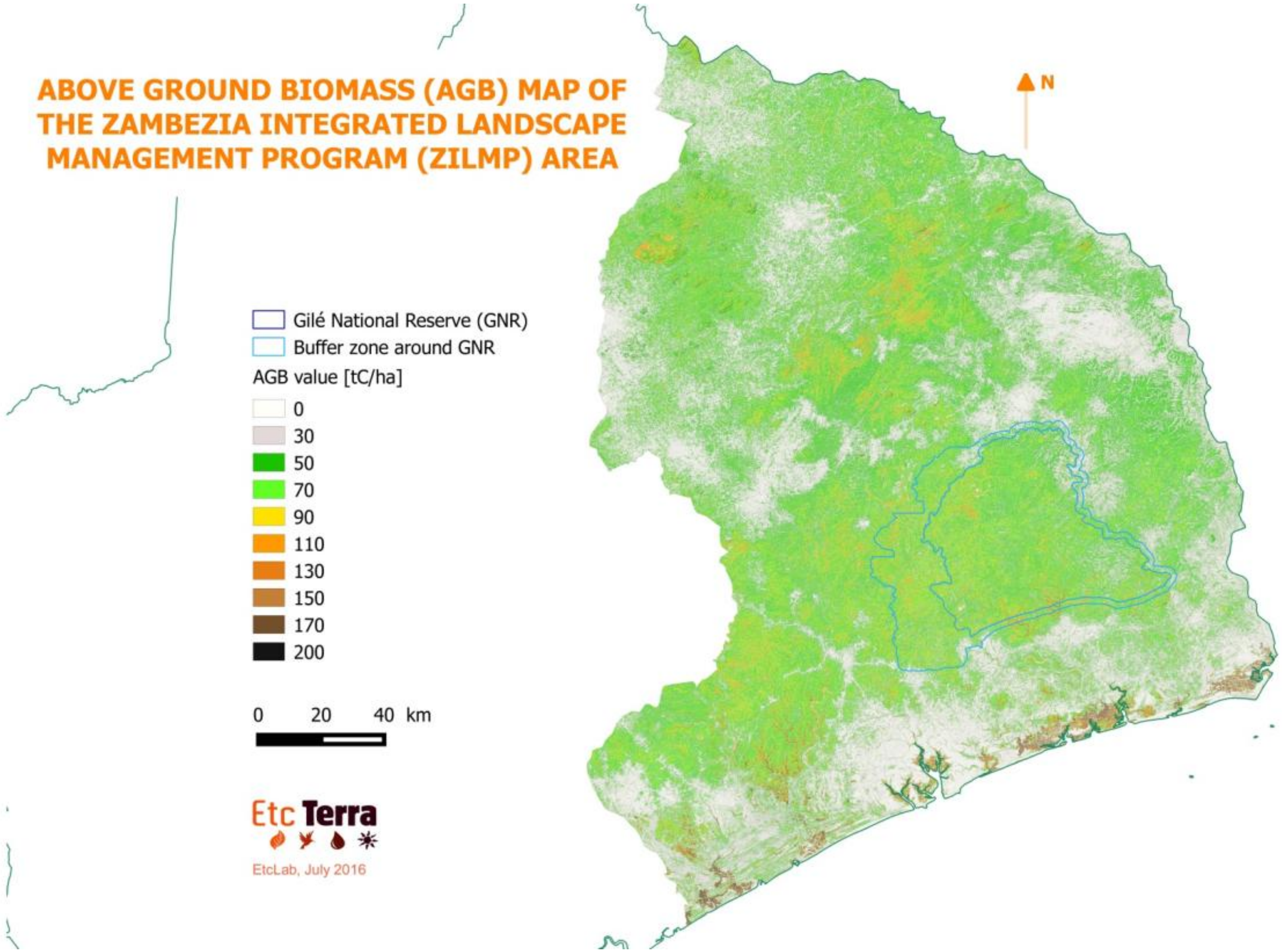


Figure 18: Aboveground carbon density map in 2013 on the ZILMP area

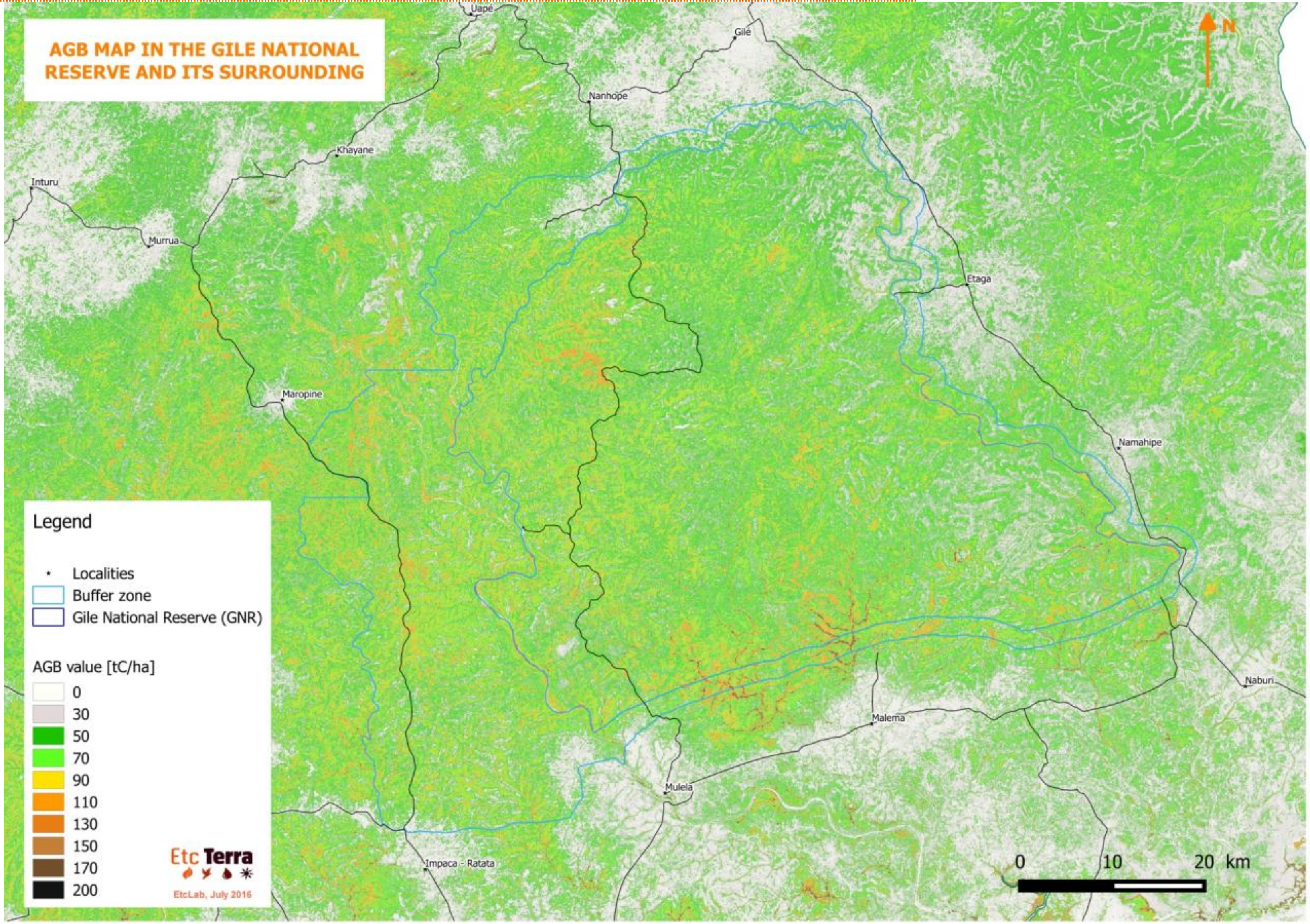


Figure 19: Above ground carbon density map in 2013 for GNR and its buffer zone

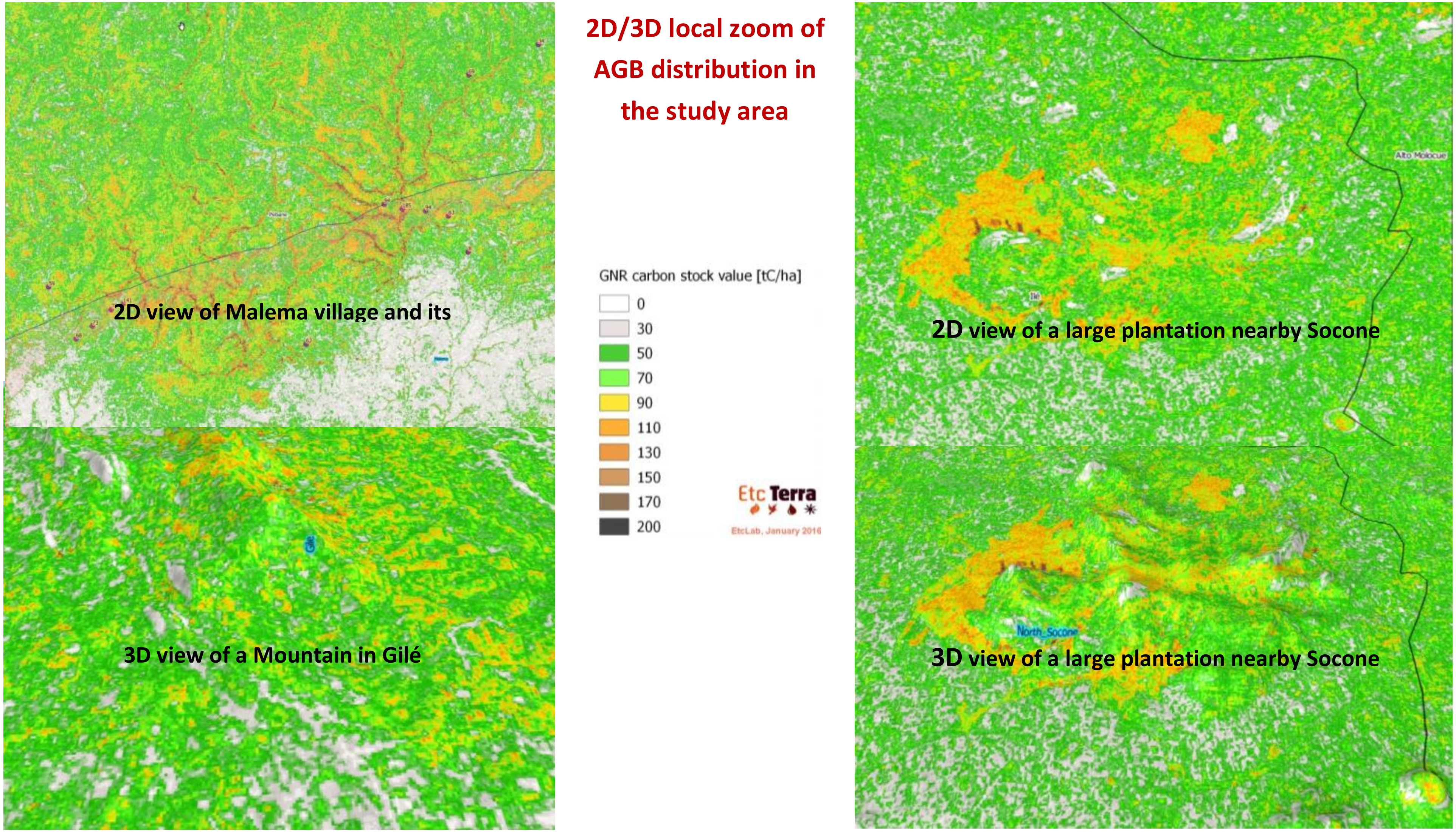


Figure 20: 2D/3D local zoom of above ground carbon density map

Envisioned used of the ZILMP AGB regional map

This innovative study on AGB mapping enables to produce a regional map that is relevant at local scale (plantations, village). It may be used in various manners to address REDD+ carbon accounting issues and more broadly for the implementation of sustainable land management strategies.

- **Forest post-stratification for emissions scenario:** The current map shows that the forest type in many parts of the ZILMP area is linked to patches of forest density. This is true for riparian forest and mangrove that show higher value compared to the Miombo forest. This knowledge makes it possible to use this ACD map as a support for forest type stratification and then to improve baseline emission calculation.
- **Identification of carbon and biodiversity hot spots:** This map displays carbon density value with a 30 m ground resolution, enabling the identification of fine scale biomass high density. These areas are of particular interest since they can sometimes be related to high biodiversity hot spots (Labrière et al, 2015). Therefore, this knowledge may help land planners and decision makers to better locate their conservation targets.
- **Regeneration and degradation studies:** the mapping of carbon density within and outside the forested area enables to study natural regeneration and fallow, as well as degradation processes. Indeed, by crossing this dataset with other spatial datasets such as historical deforestation or landscape fragmentation, one can retrieve carbon data for subtler activity data. For instance, it has been reported (Shapiro et al, 2016) that fragmentation indices are related to the level of degradation. Therefore, carbon emission from degradation can be derived from this carbon map.

5. Conclusion

The present section creates a baseline for deforestation in the Miombo forest, which is the main ecosystem and the main source of AFOLU emissions in the ZILMP program area. This baseline is based on carbon stocks estimation in above and belowground biomass in the Miombo forest and in post-deforestation lands (fields and savannas). **Analysis of other pools (soil – because of low carbon stocks and emission factors) or forest stratum (mangroves – because of very low historical deforestation rates) led to the conclusion that it was not relevant to include them in the analysis**: emissions from this pool and strata were not significant compared to emissions due to deforestation in the Miombo forest.

By projecting the mean historical level of emissions of the 2005 – 2013 period, as required by the FCPF MF (criterion 11.2), the calculated baseline is 3.3 MtCO$_2$eq per year. This baseline respects the FCPF MF requirements and can be used to draft the ER-PD. It will have to be re-assessed regularly on a frequency to be decided by the program management team.

Emissions from degradation have to be added to the deforestation baseline, if they account for more than 10% of deforestation emissions (criterion 3.3 of FCPF MF). **It may be the case**

in the ZILMP program; therefore, degradation baseline was established for charcoal production and timber exploitation (legal and maybe illegal). However, it is based on approximate factors that will have to be adjusted as the program goes on.

Activity data for degradation is mainly based on surveys, as it is difficult to study degradation with satellites images (too low resolution or spatial cover, especially on long historical periods). Hence it contains several uncertainties that have to be estimated. The inclusion of degradation in the reference emissions level of the program implies that it will be regularly monitored with field surveys on the whole program area, in order to assess its evolution. It also requires the agents of degradation to be addressed by program actions in order to ensure diminution of emissions due to degradation.

Analysis of the drivers of deforestation and forest degradation

This section aims to (i) explain the direct causes of deforestation and forest degradation in the ZILMP area; (ii) quantify emissions from deforestation and forest degradation resulting from those activities and (iii) assess the revenues derived from those activities for the agents of deforestation and forest degradation. All this data will be used in one of the next sections of this study to draw options for deforestation and forest degradation reduction.

This section builds on the study of drivers of deforestation and forest degradation by *Winrock International and Centro de Estudos de Agricultura e Gestão de Recursos Naturais* (2015) at the national scale, while focusing on the specificity of the ZILMP area.

It should be noticed that **we worked both on deforestation and forest degradation**. Those two phenomena being sometimes very hard to separate - especially given the fact that charcoal production and the opening of new fields for subsistence agriculture can be strongly linked – we had to analyze both of them. We assessed the share of emissions due to degradation in accordance with criterion 3.3 of the FCPF MF (FCPF 2013).

For several reasons, we did not use satellite images to assess the share of deforestation and/or degradation for each driver - agricultural purposes, charcoal production and/or logging. First, Winrock already did it. Second, it is too hard to distinguish those drivers from above. Consequently, although we did assess deforestation emissions with satellite data, we assessed degradation emissions linked to charcoal production and logging thanks to survey that were conducted on the ground. In order to avoid any double counting, emissions due to charcoal production were divided into two groups: (i) emissions linked to deforestation with charcoal production being only a sub-product of agriculture and (ii) emissions due to degradation for charcoal production alone.

We based our study on the list of seven drivers used by Winrock:

- S1. Large-scale agriculture.
- S2. Small-scale agriculture by smallholders including subsistence farming and cash crops.
- S3. Forestry.
- S4. Bioenergy production: fuelwood & charcoal.
- S5. Urban sprawling and Infrastructure.
- S6. Mining.
- S7. Breeding.

According to Winrock, the respective share of those drivers in deforestation and degradation process in Northern Mozambique are as follows:

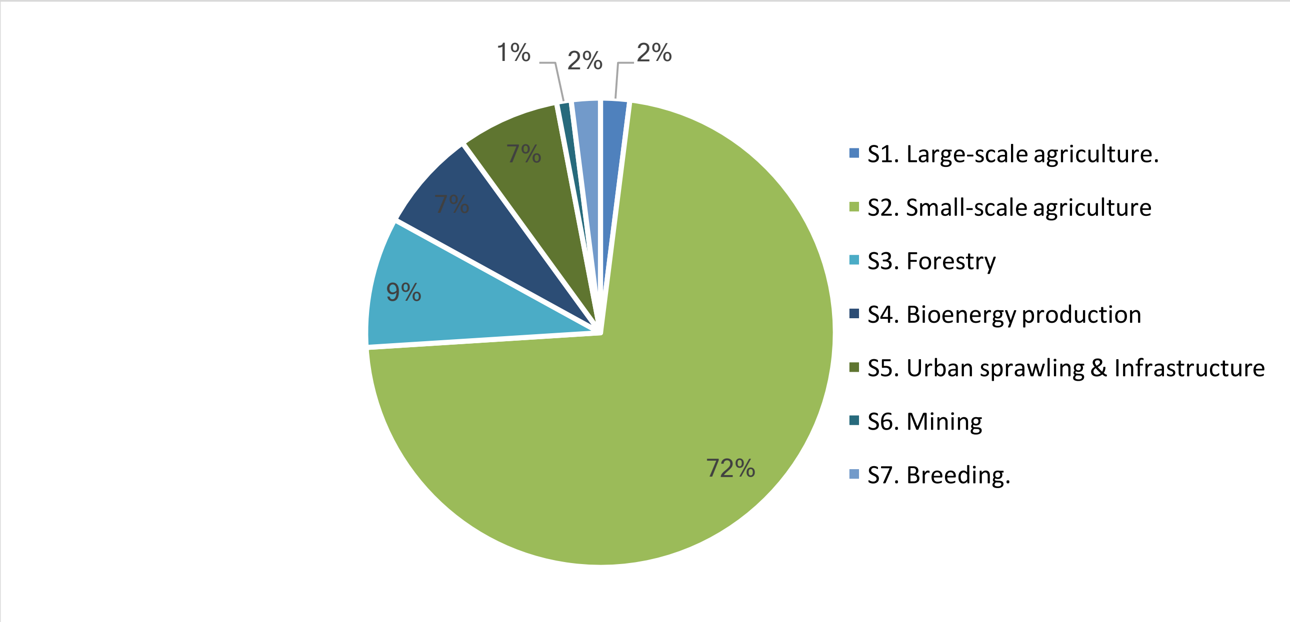


Figure 21: Part of deforestation according to driver in the North zone of Mozambique. Source: Winrock, 2015

Starting from this assumption, we focused our analysis on agriculture (both large and small scales), forestry and bioenergy production. Since they are less significant in the ZILMP area, the other drivers are described more quickly.

Underlying causes are treated within each driver analysis. But demography being a very important one, we made an independent section on it.

For this section, both qualitative and quantitative data was gathered through field systematic surveys, field interviews, interviews with major economic stakeholders in the program area and literature review.

1. Agriculture

According to *Winrock International and Centro de Estudos de Agricultura e Gestão de Recursos Naturais* (2015), whereas large-scale agriculture is responsible for only 4% of deforestation emissions, small-scale agriculture is the most important driver at national scale, accounting for 65% of deforestation emissions. Agreeing on this, we will focus our analysis in the ZILMP area on small-scale agriculture.

Before that, we should consider national statistics on Mozambique's agricultural export in order to (i) assess the potential impact of internationally traded commodities on deforestation and (ii) infer the best value chain to be developed in the ZILMP area. This section will also show the link between food crops and deforestation at national scale.

1.1. Agriculture at national level

1.1.1. General Agricultural Profile of Mozambique

The agricultural sector employs more than 70% of the Mozambican population and accounts for 24% of the country's GDP. In 2014, there were 4.3 million farms in Mozambique - 4.2 of which were smallholdings that were cultivated by households composed, on average, of 5 people.

The total cultivated area is estimated to be 5.1 million ha; smallholdings account for 96% of this surface (DPCI 2014). The smallholder farming systems are capital extensive and use few inputs: less than 5% of households use mineral fertilizers. Only 2% of them use animal traction, the other 98% relying on hand hoeing: the main available resources for farmers are their land and labor (Leonardo et al. 2015).

1.1.2. Cash Crops dynamics over the last ten years

According to UNCOMTRADE (see figure below), here are the main agro-exports patterns for Mozambique between 2004 and 2014:

- Agricultural exports have **tripled**.
- **The first sector is sugar**, but it is very dependent on EU-ACP agreements (export quotas), which should be reformed in October 2017.
- **A strong momentum remains on sesame exports:** the value of sesame exports between 2004 and 2014 has been multiplied by 10, benefiting from favorable conditions on global markets and easy technical adoption by smallholders.
- The beans sector is also growing relatively steadily.
- The 'fish and sea food' sector was very affected by the 2008 crisis. The sector is dominated by shrimp exports towards, mainly, the European market. Falling prices on global market, combined with high production costs and diseases in Mozambique, caused a heavy drop in Mozambican exports[4].
- **The 'traditional' Mozambican agricultural exports that are cashew, cotton and tea, have been characterized by erratic trends and difficult restructuration.**

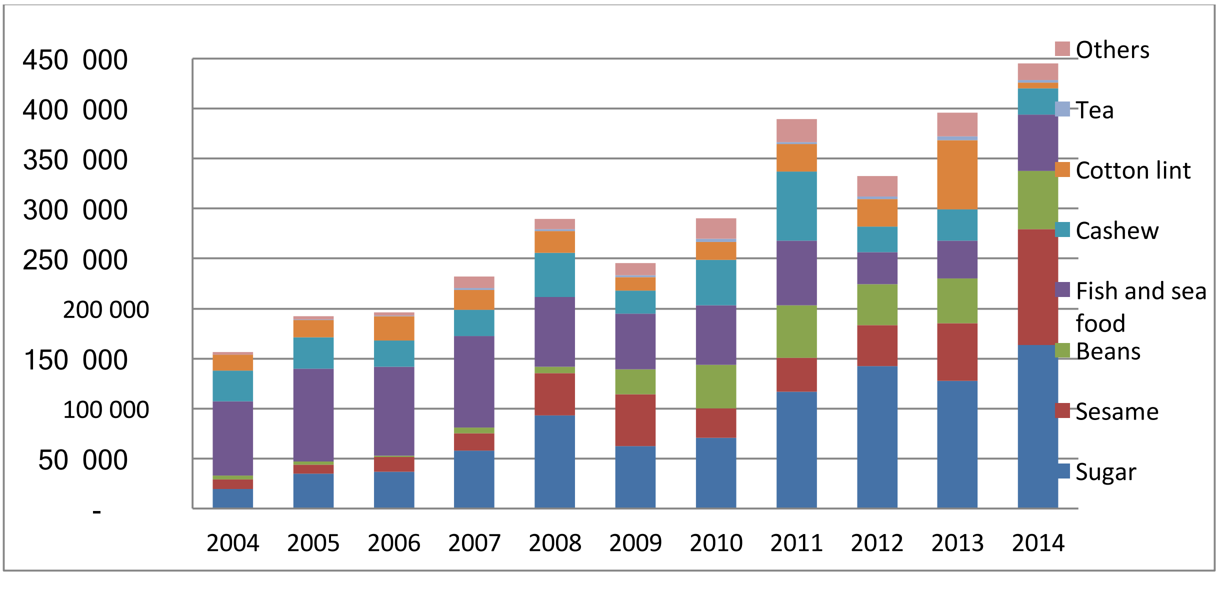


Figure 22: Mozambique agricultural exports, by product, in kUSD. Source: UNCOMTRADE

4 From: http://transparentsea.co/images/4/40/Mozambique_fisheries_report_final.pdf

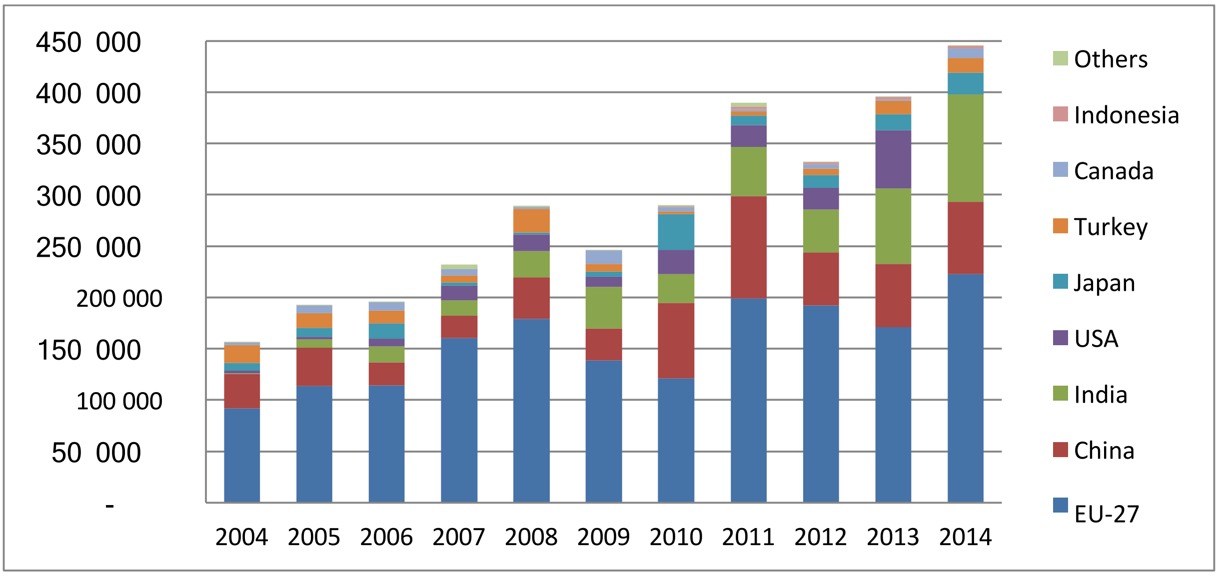


Figure 23: Agricultural exports of Mozambique by destination, in kUSD. Source: UNCOMTRADE. Data processing: Rongead & Etc Terra

According to Figure 23, Mozambique's agricultural exports are mainly oriented towards the European Union (EU), which is especially due to sugar quotas and EBA agreement (Everything but arms). Over the period, the most important evolution is related to the increase of export towards China and India. In particular, sesame and cashew exports are nearly exclusively for Asian markets.

1. Annual cash crops

Following recent studies mentioning **annual cash crops as indirect deforestation drivers** (Winrock International and Centro de Estudos de Agricultura e Gestão de Recursos Naturais 2015), we had a close look on global market patterns on annual cash crops that exist in the ZILMP area: cotton, tobacco and sesame seeds.

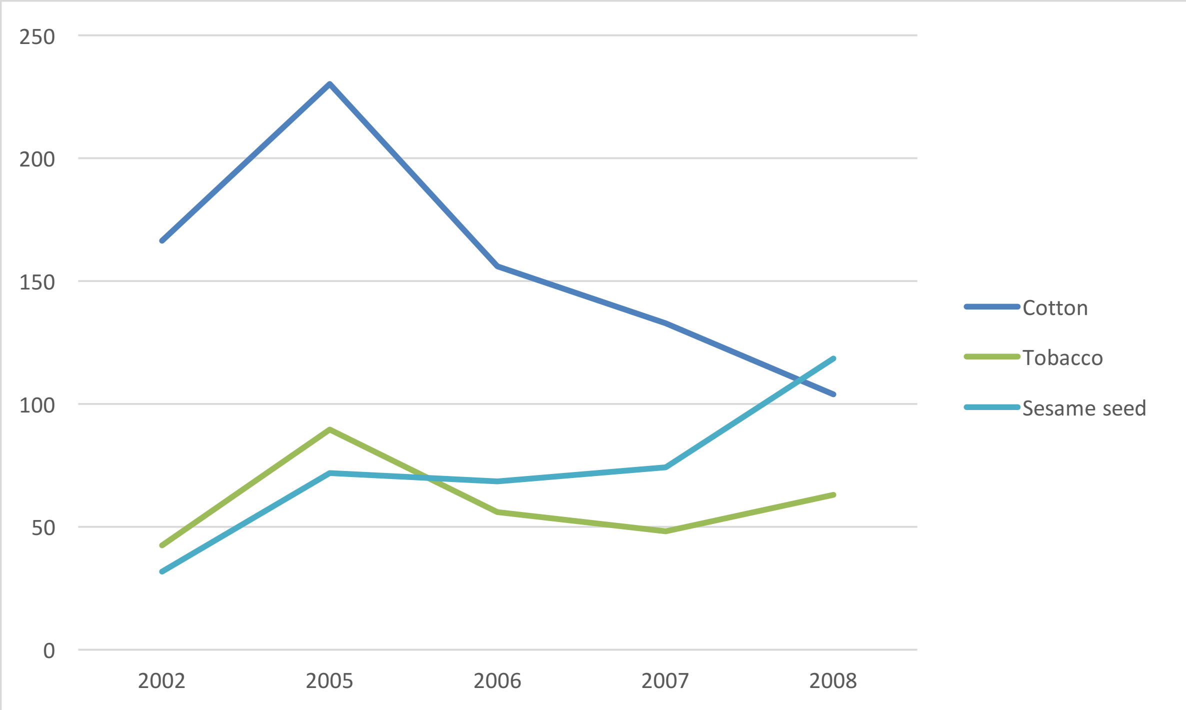


Figure 24: Cultivated areas of annual cash crops in Mozambique, in kha. Source: Anuário de estatísticas agrarias (data available only for 2002-2008 period)

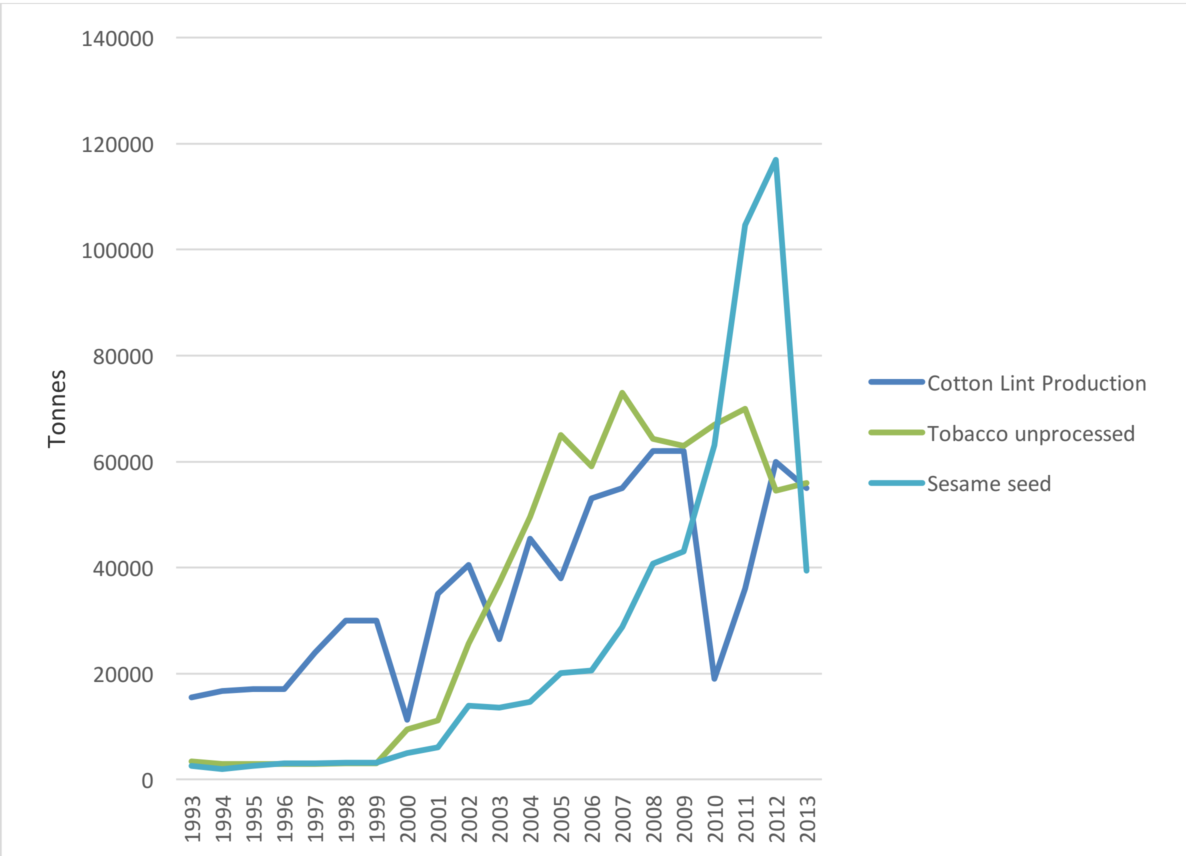


Figure 25: National Production of Cotton Lint, Tobacco unprocessed and Sesame Seed in tons. Source: FAO Stat

The data in the graphs above have to be analyzed with caution, but they show some important trends:

- **Tobacco production has been quite stable since 2004**, with 60,000 to 70,000 tons of unprocessed tobacco.
- **Cotton lint production has been relatively volatile** over the 1993-2013 period.
- **Sesame seed is a very attractive cash crop for small holders; its annual growth has been strong since the 2000's**.

Those trends can be explained both by international demand and local value chains factors.

Tobacco is one of the most important agricultural export crops in Mozambique. From 1993 to 2003, production has rapidly increased: from 3,000 tons to 60,000 tons. Smallholders are responsible for the majority of the production. However, the tobacco production system is concessionary, with farmers not receiving any price incentives under the prevailing cost structure in the value chain (MAFAP/SPAAA, February 2013). The monopsony system and the vertically integrated value chain are not advantageous for smallholders. Consequently, since 2004, production and cultivated areas have remained quite stable.

Regarding **cotton**, it is worth notifying that the international market is not in favor of African countries, which are facing structural weaknesses - from production to cotton processing - and competition from American subsidies. The local value chain is based on a monopsony system, in which ginning companies are granted concession rights as cottonseeds exclusive buyers in their respective area of concession (MAFAP/SPAAA, analysis of incentives and disincentives for cotton in Mozambique, 2012). Smallholders dominate the production (90%) but farm gate prices are not attractive - because of the monopsony system, the high level of taxes and excessive ginning costs.

Sesame became a very interesting cash crop for smallholders. The sector benefits from strong international demand and is easy to crop - sesame cultivation support low level of rains, poor soils and is not labor intensive. The local value chain is quite competitive with exporters (e.g. OLAM) directly collecting and cleaning sesame seeds before exporting them on the international market. Since 2000, the international market increased (Figure 27), with significant changes in terms of prices and volumes (Figure 28). In Mozambique, sesame seeds production also started to grow in 2000.

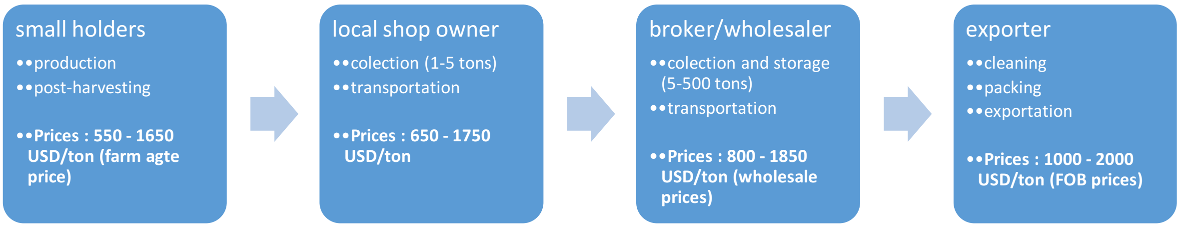
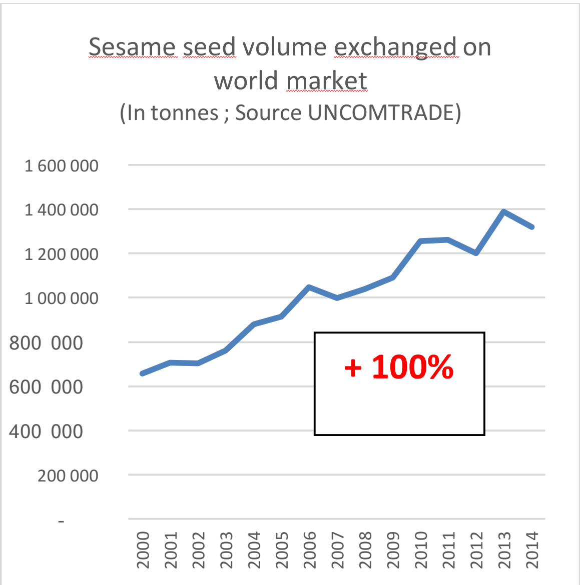


Figure 26: Description of the local sesame value chain



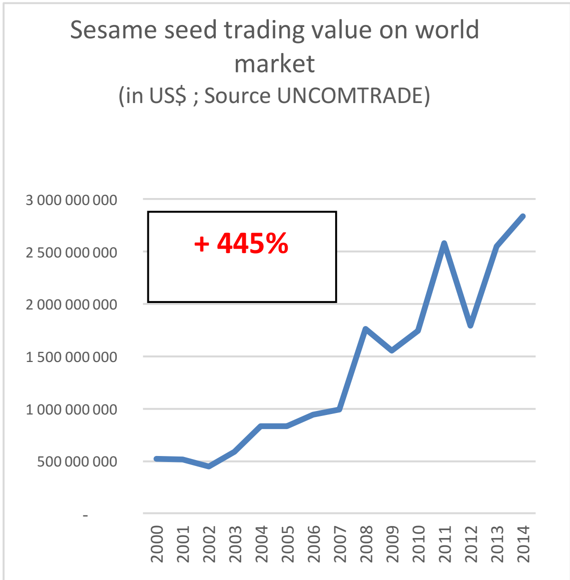


Figure 27: Dynamism of the sesame seed international market

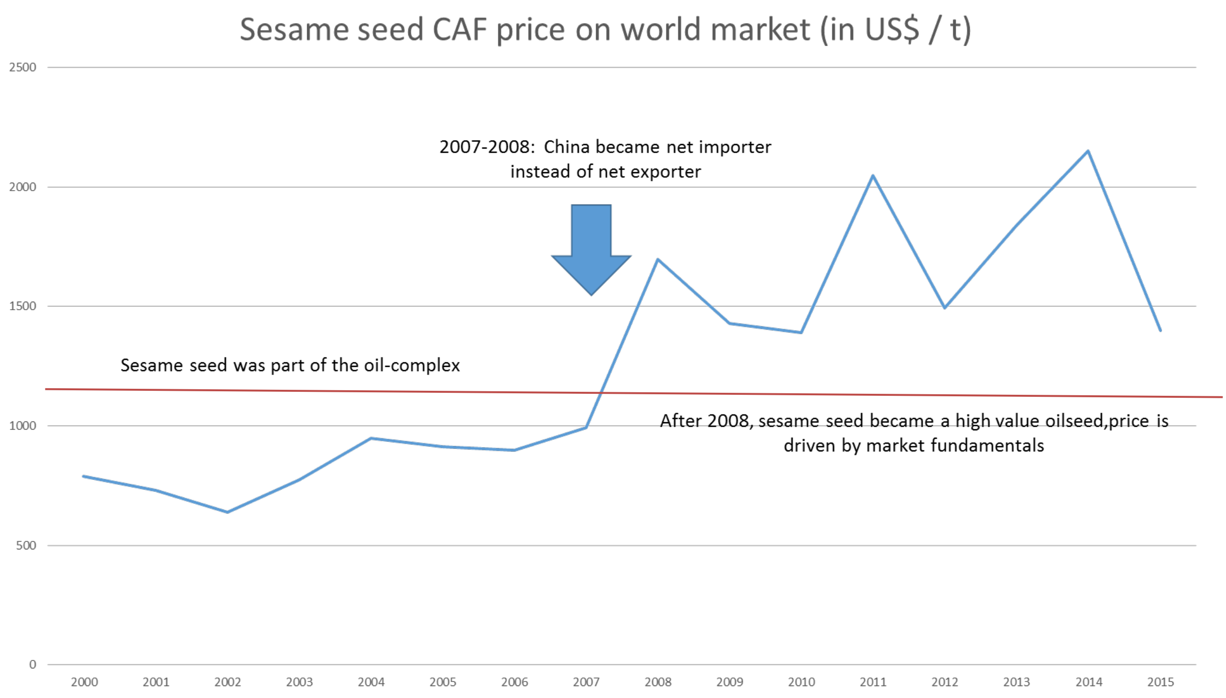


Figure 28: A change in market pattern for sesame seeds

2. Perennial cash crops

In Mozambique, **cashew** is the main perennial cash crop.

Cashew is the main historical agro-sector in Mozambique. In the 1960's, Mozambique used to be one of the first world raw cashew nut (RCN) producer and RCN processor. Since it lost its place in the 1970's, it still has not regained its initial potential and re-launched its production.
The estimated area for cashew production is 16 millions ha, for a production of 35,000 tons in 2015 - which represents less than 1% of the world production. The processing capacity is 46,000 tons of RCN per year and the processing ratio is more or less 50%. In 2015, Mozambique exported 3,500 tons of cashew kernels. Local consumption averages 500 tons.

The sector is facing many constraints: old orchards with very low productivity (less than 100 kg/ha), phytosanitary problems, unsuitable processing sector, high marketing costs, market distortions due to the 18% tax and the ban on export during the trading period, as well as inefficiencies in public support by INCAJU (very low dissemination of improved cashew trees and of subsidized chemicals for treatment). Those factors have contributed to the decline in national production, as shown in the graph below.

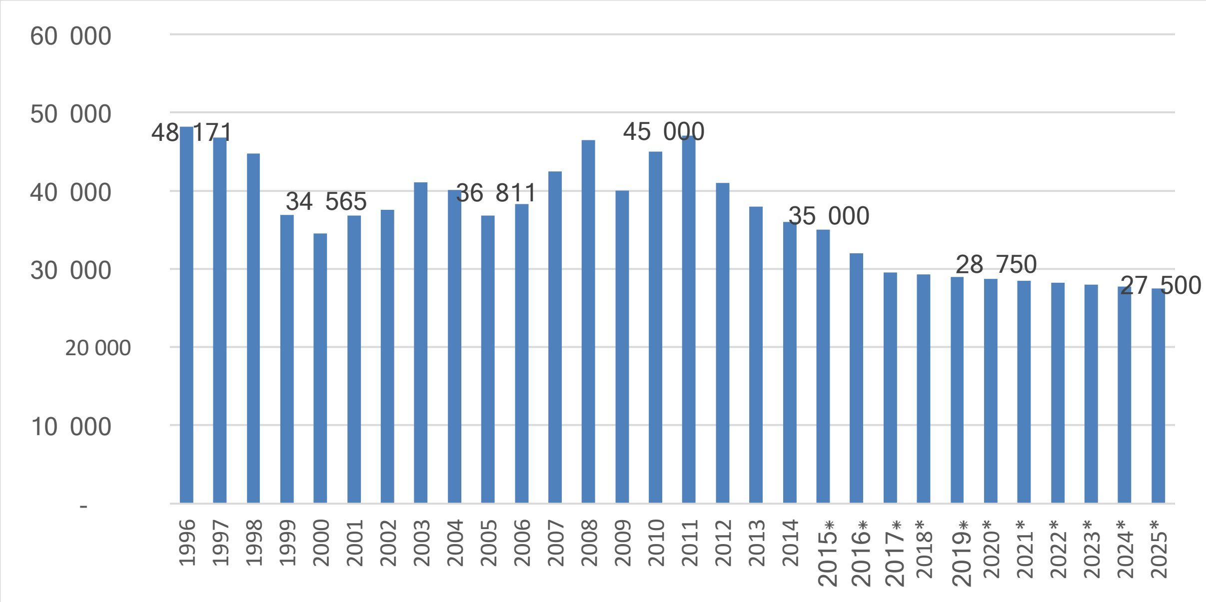
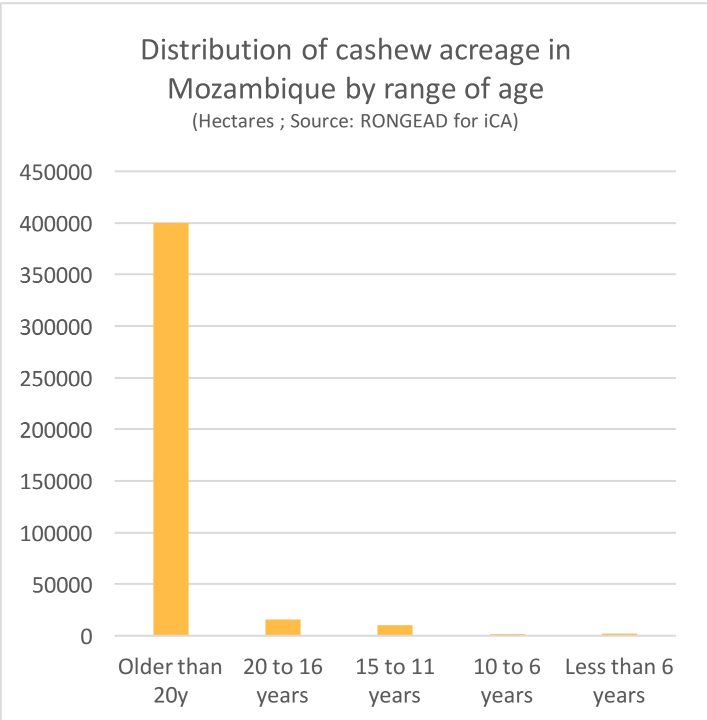


Figure 29: Mozambique's cashew production, in tons of RCN, including forecasts. Source: Rongead

Most of the cashew orchards are old and not productive - most of the trees are older than 20 years. Cashew trees exist everywhere in Mozambique, but the production is concentrated in Nampula Province.



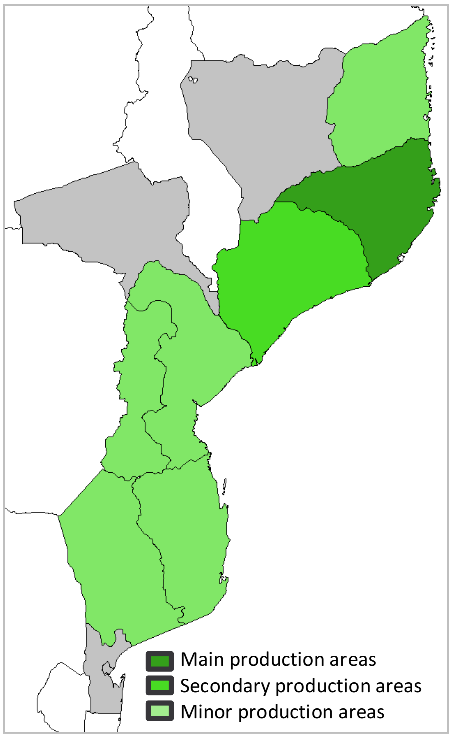


Figure 30: Left: Cashew surface in ha by age classes. Source: Rongead for ACi. Right: Map of production zones

Most of the RCN that are produced by Mozambique are sold to Asian countries (India and Vietnam), which have based their competitive processing sector on the imports of RCN from African countries. In 2014, Mozambique exported 15 100 tons of RCN.

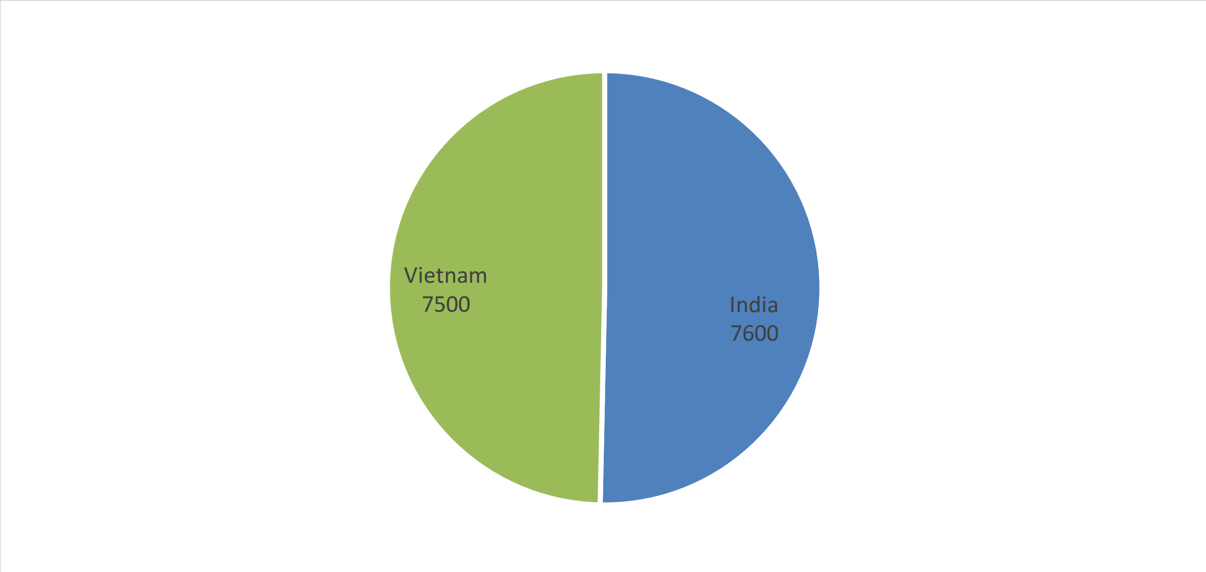


Figure 31: Mozambican RCN export by destination in 2015, in tons. Source: Rongead

Mozambique also exports cashew kernels thanks to local processors, which adds value to the local economy.

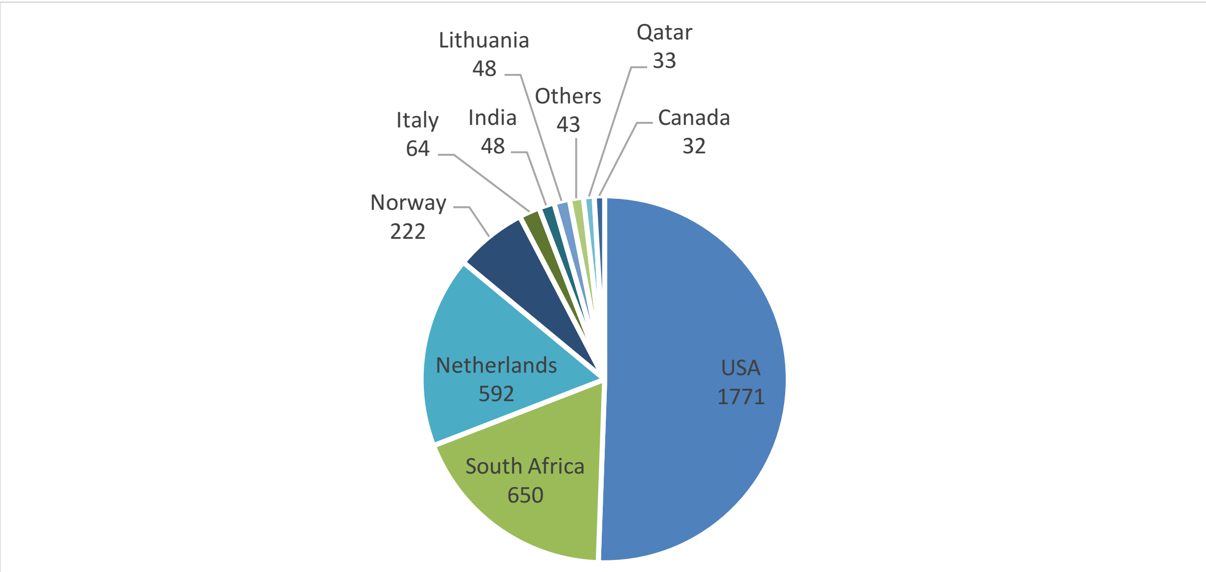


Figure 32: Mozambique cashew kernels exports by destination in 2014 in tons. Source: Rongead

1.1.3. Cash crops development and deforestation in the coming years

Starting from the evolution of global market and Mozambique's main agricultural resources, as presented above, we tried to assess the potential of new deforestation due to cash crops development in Mozambique in the years ahead.

The **sugar sector** is based on heavy industrial structures, which will require major investments (land, irrigation). The potential end of the ACP / EU quotas in 2017 may slow down its development. Therefore, **sugar should not be a major driver of deforestation** in the coming years.

Since sesame is space consuming – average yields are below 300 kg/ha – the development of its exploitation could easily exacerbate deforestation. However, sesame is usually grown on poor soils and is used at the end of crop rotations. **It is therefore unlikely that sesame has a significant impact on deforestation in Mozambique**.

Soya has also been described as a potential driver of deforestation in the coming years. As Brazilian chicken is being rapidly substituted by Mozambican one, one could expect an increase in Mozambican soya production for chicken feed. If we have indeed observed an increase in surface under soya, it is still moderate. So far the increased need for soya has been covered by a rapid increase in imports from Brazil. To sum up, Brazilian chicken imports are substituted by Brazilian soya imports. We do not see this pattern changing in the coming years as there is no restriction on imports of soya from Brazil (contrarily to chickens which are subject to quotas) and Brazilian soya is very competitive. Moreover, Mozambican crushing industry is devastated, important investments would be needed for an upgrade and we do not see it coming shortly.[5]

Since we do not foresee any significant increase of the other export crops (tobacco, cotton, cashew) in Mozambique, **we conclude to a general low impact of cash crops on deforestation in the coming years**.

We should nevertheless carefully distinguish small farming crops (cashew, cotton, tobacco) from plantations crops (tea). Admittedly, the rehabilitation of industrial plantations could have an effect on deforestation, but to a reasonable extent.

Finally, the crisis in the **'fish and sea food'** sector may have indirect effects on deforestation, especially in coastal areas, resulting from an increase of subsistence farming as a solution to job losses in the shrimp industry.

Key points

Cash crops are not a significant driver of deforestation in Mozambique, neither today nor and in the coming years.

Sesame is a strategic value chains sectors for smallholders: it is a dynamic market and can easily be integrated into conservation agricultural practices (sesame is undemanding and

[5] We could roughly estimate the area needed to supply the entire national production to 60,000 ha; which is quite small at national scale

easily integrated into rotations). To a lesser extent, cashew, as an undemanding tree species, is also a relevant value chain to be supported.

1.1.4. Food crops dynamics and deforestation

The increase of agricultural land areas in Mozambique is mainly due to subsistence agriculture. The two main food crops are cassava and maize. According to the *Anuário de Estatísticas Agrárias 2012 – 2014* (DPCI 2014), in 2014, maize occupied an area of 1.7 million ha for a production of 1.4 million tons, while cassava occupied 870,000 ha for a production of 4.1 millions tons.

Understanding the development dynamics of the two main cultivations is complex: most of the production is realized in mixed-fields, with yields being difficult to assess in a smallholder context - notably because of the importance of self-consumption and of planting and harvest times being spread over time (for cassava). Available statistics are therefore still subject to discussions. The following table - constructed on the basis of FAO data for the period 1990-2012 and incorporating the DPCI data for the 2012-2014 period - should be considered with a full understanding of those limits. Figure 33 **clearly shows the role of maize in the increase of agricultural surfaces**.

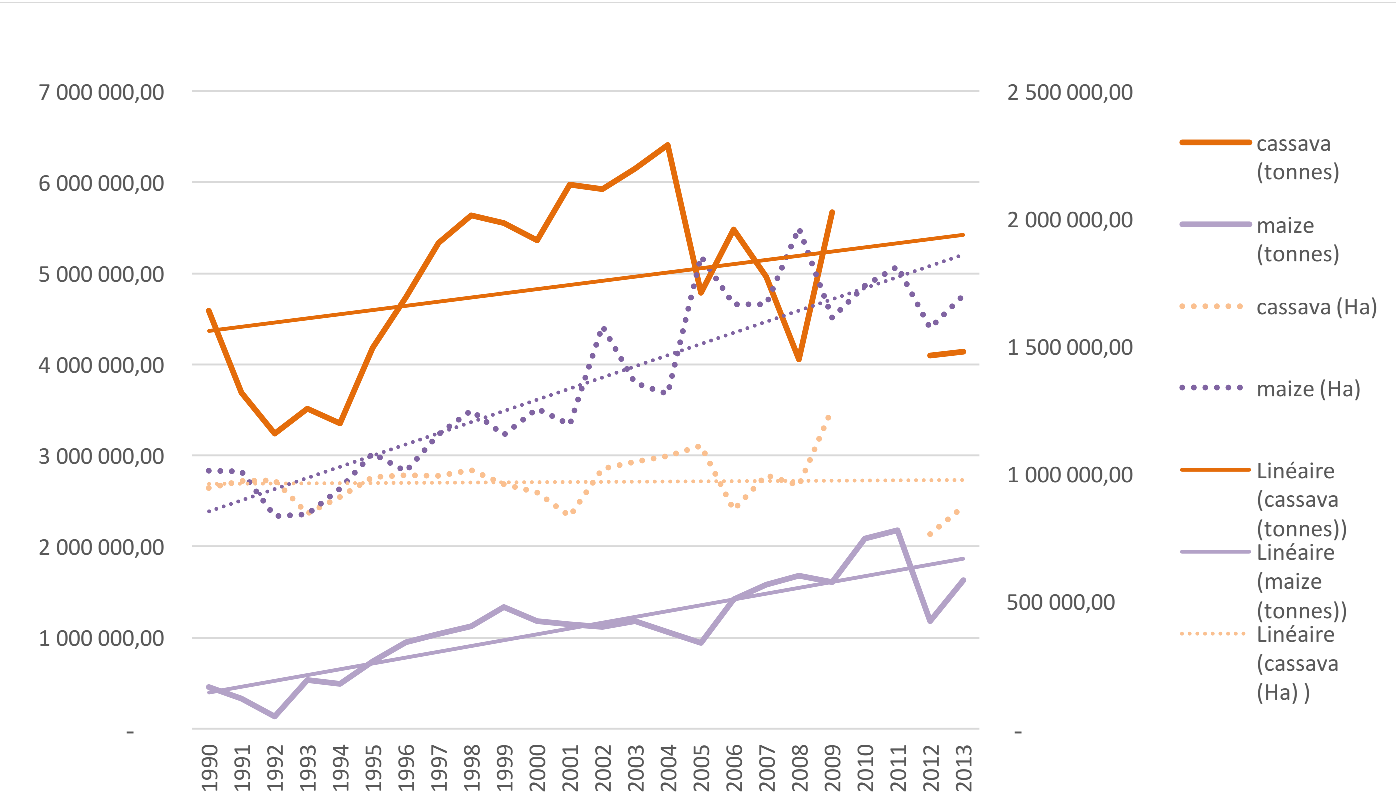


Figure 33: Evolution of surfaces and productions across the country for maize and cassava. Source: FAO Stat and DPCI. Data processing: Rongead & Etc Terra

The main practice for maize and cassava cultivation is “slash and burn” agriculture, farmers looking for soil fertility and optimized work productivity in forestlands – whereas savanna lands have poor soil fertility and high amount of weeds, leading to higher workload for smaller yields. Farmers use to grow recently deforested land, until soil fertility depletion or excessive presence of weeds, after which they abandon the field as a ‘ruinas’. Afterwards, they have to open a new field, by deforesting a new part of forest: this dynamic explains continuous extension of deforestation around rural localities that are mostly inhabited by farmers. As such, **the increase of maize cultivation, and the subsequent increase of land use, is the main driver of deforestation at national scale.**

Nevertheless, in some areas and particularly in the ZILMP area, **it is difficult, on the field, to separate maize and cassava. Small producers are used to culture associations and rotations** within a same cleared plot. For example, a newly cleared parcel would be sown with maize, associated with several species of beans *(vigna* or *phaselus).* After a year, the association “maize / cassava” would be introduced and, after two or three years, the plot would slowly evolve into a cassava quasi-monoculture area. Although the two crops are very closely linked, the first year of cultivation is restricted to maize only because it is more demanding than cassava and needs to benefit from the forest fertility; cassava is introduced later. **Therefore, for the ZILMP area, it is more accurate to say that the couple “maize – cassava” is the first driver of deforestation**.

Key point:
The “maize-cassava” couple is the first driver of deforestation but it also plays a key role in the population's diet: those two crops alone represent more than 50% of caloric intake across the country, according to FAO 2011 Food balance sheet.
Improving agricultural practices, on the basis of agro-ecology and taking into account the constraints related to low labor productivity, is a strategic option to fight deforestation.

1.2. Agriculture in the ZILMP area

In the ZILMP area, the general characteristics of agriculture are the following:

- Large-scale agriculture is almost nonexistent. The restoration of an industrial tea plantation in the district of Ilé is a limited deforestation factor.
- The “cassava-maize” couple is the main driver of deforestation, through “slash-burn” agriculture.
- Sesame and beans are important cash crops.
- Cashew represents a fairly stable income in 3 districts of the ZILMP area.

1.2.1. Large-scale agriculture in the ZILMP area

We were not allowed to access the agricultural DUAT registry describing all the conceded DUATs since the promulgation of the Land law, but we were allowed to access the registry of recent large-scale project, thanks to the *Centro de Promoção da Agricultura* (CEPAGRI).

In the recent years, only one DUAT was granted in the ZILMP area for large-scale agriculture, to *Cister* company, for 250 ha of beans near Nauela in Alto-Molocué district. Before that, **few large-scale exploitations were settled in the area** and most of them were created during colonization: coconut plantations in Pebane and Maganja da Costa (today abandoned); irrigated perimeter for rice in Maganja da Costa (partly rehabilitated). Our analyses on the ground suggest that those **large-scale exploitations are not responsible for current deforestation** - with one exception, *Chá de Socone*, north of Socone in the Ilé district. This tea plantation, created during colonization, was abandoned during the war; forest regrew over the plantation, which is now being restored trough forest clearing.

Thus, regarding large-scale agriculture, the ZILMP area differs a lot from others districts of Zambézia such as Gurué, Mocuba or Morrumbala, where large-scale agriculture is important. Investors for this type of agriculture would rather invest in those above-mentioned districts, where agricultural services already exist and agronomic conditions are better. Nevertheless, CEPAGRI, on the basis of the agro-ecological zoning, is promoting to investors the Pebane district as the best district in Zambézia in terms of available surface for large-scale agriculture.

Figure 34: Restoration of an industrial tea plantation in Socone, Ilé District

1.2.2. Small-scale agricultural production in the ZILMP area

1. Surfaces involved in agricultural production in the ZILMP area

The estimation of relative areas by specific culture is a delicate exercise. In order to calculate the share of each production, we used two sources of information: (i) production statistics elaborated by *Serviços Distrital das Atividades Económicas* (SDAE) and (ii) estimates based on local consumption in the area. In the section on demography, we also tried to model the total agricultural land needed, based on plot surveys of smallholder strategies.

According to SDAE statistics

The areas cultivated in the seven districts amount to 514,722 ha – which is, approximately, 27% of the non-forest area in the ZILMP area. The area covered by cassava and maize crops accounts for more than 50% of the agricultural lands, followed by protein crops (several varieties of beans and groundnut). The area that is dedicated to rice is mainly concentrated in the district of Maganja da Costa (30,000 ha of 39,000 ha total). The "maize – cassava" couple occupies 56% of the agricultural area.

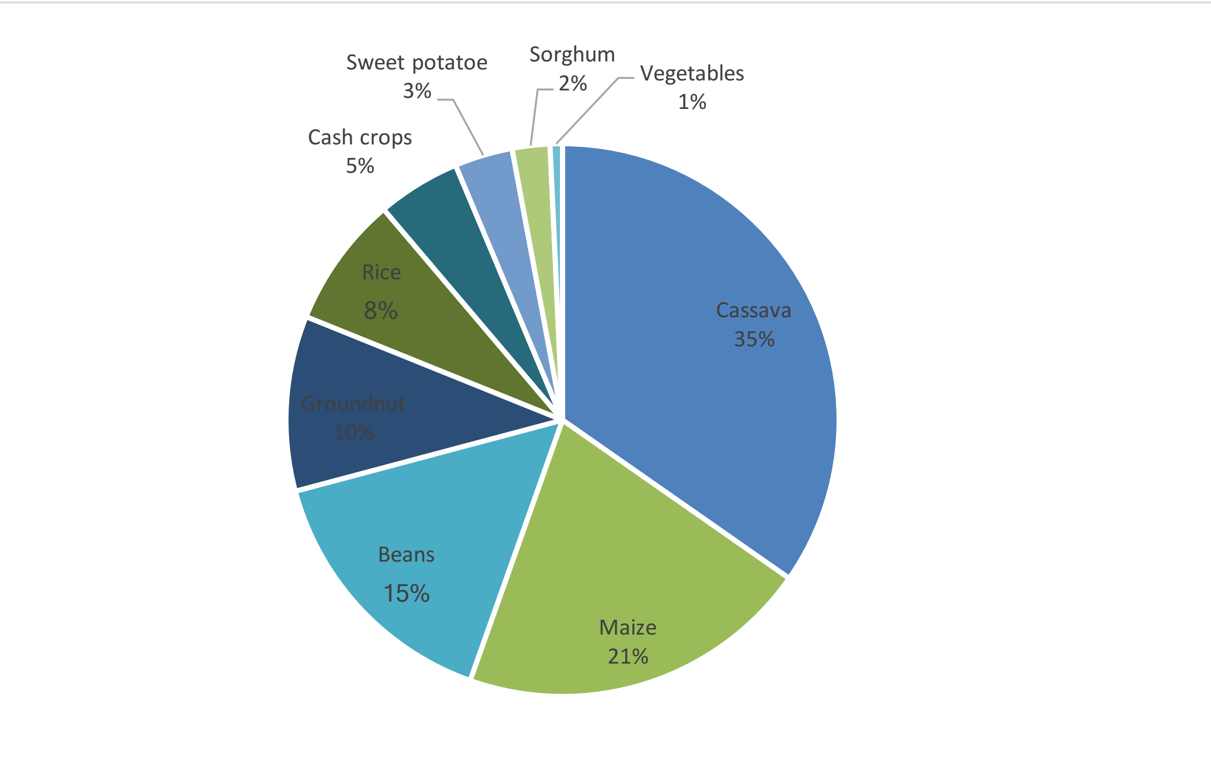


Figure 35: Breakdown of surfaces by crop in 2014 in the ZILMP Area. Source: SDAE

According to estimates based on local consumption using FAO 2011 Food Balance sheet (see Table 26).

We have selected the main products consumed and retained those produced in the area. Based on average yields observed by *Agrisud International* in the area, we were able to estimate the surfaces needed to cover the consumption of an estimated population of 1.2 million people in the 7 districts (see Table 27). According to this calculation, the total land surface for food production is 537,970 ha - i.e. 29% of the non-forest area of the ZILMP area. This number does not include non-food crops, but it is already bigger than the SDAE number that incorporates them (25,080 ha).

Table 26: Food balance sheet of Mozambique. Source: FAO Stat

Mozambique Food Balance Sheets - 2011 - source : FAO Stat																
												Population (Thousand)			24581.0	
Single Items	Domestic Supply					Domestic Utilization						Per Capita Supply				
	1000 Metric tons											Total		Prot.	Fat	%
	Prod.	Impo.	Stock Var.	Exp.	Total	Food	Food Manu	Feed	Seed	Waste	Oth. Uses	Kg / Yr	KCal / Day	Gr / Day	Gr / Day	% Kcal/Day
Cereals - Excluding Beer	2842	954	-235	63	3498	2728	33	512	56	169		111	925	23.3	6.6	40,8
Wheat and products	20	410	90	51	470	459	0		1	10		18.7	140	4.1	0.5	6,2
Rice (Milled Equivalent)	181	359	31	0	570	528	11		13	19		21.5	211	4.1	0.3	9,3
Maize and products	2179	160	-250	12	2077	1430		500	31	116		58.2	467	12.3	5	20,6
Millet and products	52	0	-6	0	46	41			2	3		1.7	14	0.2	0.1	0,6
Sorghum and products	410	4	-100	0	314	268	3	12	9	21		10.9	92	2.6	0.8	4,1
Starchy Roots	11152	28	-1800	0	9380	6179		1090	14	2097	0	251.4	731	6.7	0.8	32,2
Cassava and products	10094	0	-1800	0	8294	5204		1090		2000	0	211.7	632	5.2	0.6	27,9
Potatoes and products	190	28		0	218	193			14	11	0	7.9	15	0.3	0	0,7
Sweet potatoes	860				860	774				86		31.5	83	1.1	0.2	3,7
Pulses	499	0	0	71	428	327			80	21		13.3	124	8.1	0.6	5,5
Beans	200				200	141			53	6		5.7	54	3.5	0.3	2,4
Pulses, Other and products	299	0	0	71	228	186			27	15		7.6	70	4.6	0.3	3,1
Oilcrops	621	9	0	46	584	34	513		31	5		1.4	13	0.6	1	0,6
Soyabeans		2			2	2						0.1	1	0.1	0	0,0
Groundnuts (Shelled Eq)	67	1		10	58	14	20		22	2		0.6	8	0.4	0.7	0,4
Vegetable Oils	140	148	-15	7	267	206					62	8.4	203	0	22.9	9,0
Soyabean Oil		45	-15		30	30						1.2	30		3.3	1,3
Groundnut Oil	9	0		0	9	9						0.4	8		1	0,4
Sunflowerseed Oil	6	13	0	3	17	17						0.7	17		1.9	0,7
Cottonseed Oil	8	3	0	0	11	11					0	0.5	11	0	1.3	0,5
Palm Oil		84	0	0	83	53					31	2.1	52		5.9	2,3
Sesameseed Oil	32				32	32						1.3	32		3.6	1,4
Maize Germ Oil	25		0		25	25						1	25		2.8	1,1
Oilcrops Oil, Other	39	2	0	0	41	10					31	0.4	10	0	1.1	0,4
Vegetables	476	23		1	498	448				50		18.2	12	0.6	0.1	0,5
Tomatoes and products	195			0	195	175				20		7.1	4	0.2	0	0,2
Onions	80	19		0	99	89				10		3.6	4	0.1	0	0,2
Vegetables, Other	201	4		1	204	184				20		7.5	5	0.3	0	0,2
Fruits - Excluding Wine	673	24		51	645	593				51		24.1	31	0.5	0.2	1,4

Table 27: Assessment of the required area to cover food needs. Source: Rongead & Etc Terra

	Annual utilization (food) (tons)	Equivalent surface (ha)
Cassava	254,040	317,550
Maize	69,840	87,300
Sweet potatoes	37,800	37,800
Pulses, Other and products	9,120	30,400
Sorghum	13,080	26,160
Beans	6,840	22,800
Potatoes	9,480	9,480
Millet	2,040	4,080
Groundnuts (Shelled eq.)	720	2,400
Total staples crop		537,970

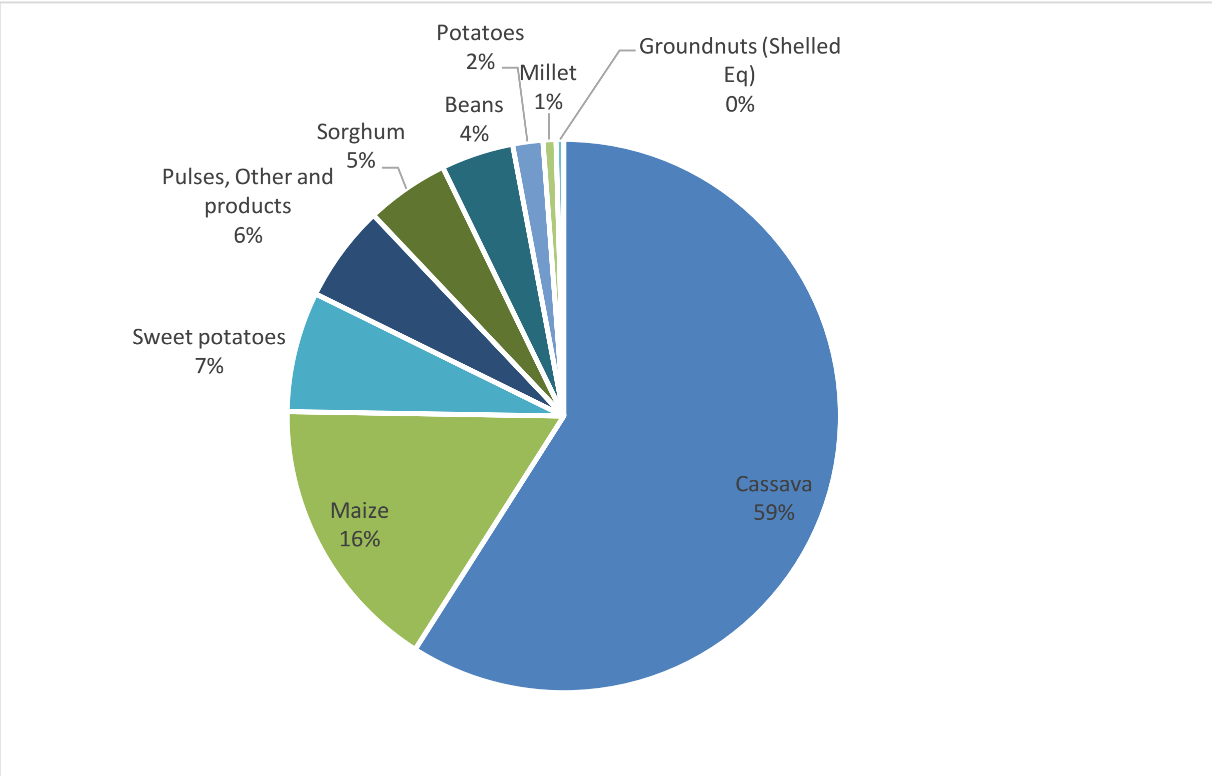


Figure 36: Breakdown of surfaces by crop in 2014 in the ZILMP Area. Source: Rongead & Etc Terra

This estimate according to consumption patterns strengthens the position of the **maize - cassava couple as the primary driver of land occupation**; the couple occupies 75% of surfaces.

2. Description of the production systems in the ZILMP area

Field visits easily confirmed the statistical description above: the couple "**maize – cassava" is at the heart of the production system in the ZILMP area.** The newly cleared areas are, in most cases, planted in maize associated with beans. Then cassava is planted progressively, over several cycles, until occupying an entire plot. After exhaustion or excessive presence of weeds, the plot becomes a '*ruinas*' and is abandoned.

As stated recently by (Leonardo et al. 2015) for Manica province, or before by Baudron (2009) for the Gilé District, and confirmed by Agrisud survey around the GNR (see below), **maize cultivation by smallholders is not constrained by land but by labor availability during peak season, especially for weeding.**

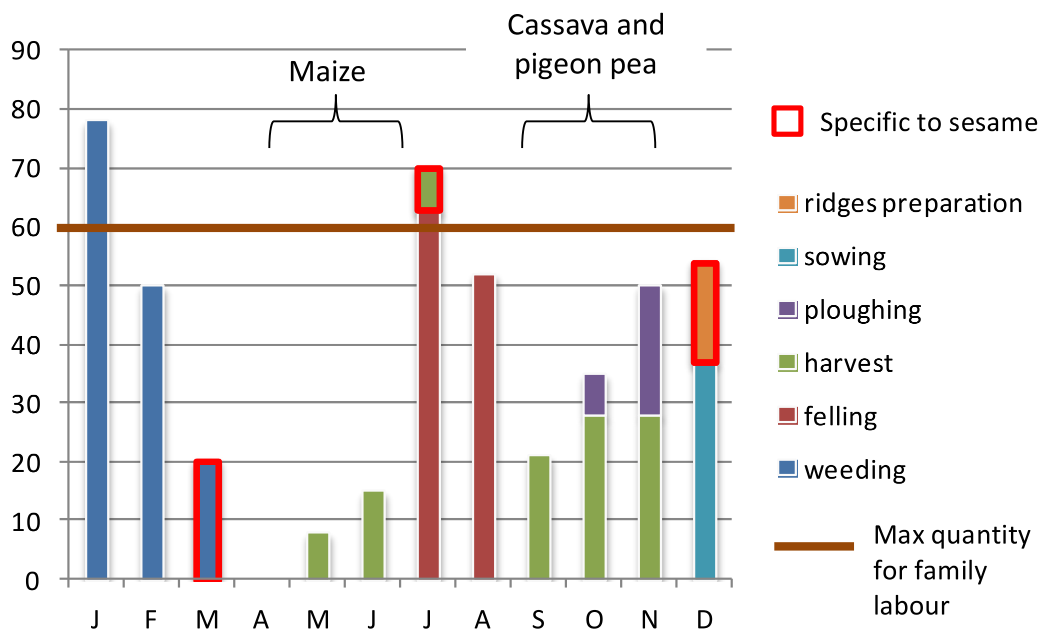


Figure 37: Agricultural workload along the year in the Gilé district. Source: Lamarre 2015a

In the context of the ZILMP, with no access to external inputs (no animal traction, no mechanization, no fertilizers…), and as long as forest land is available, the easiest way to increase labor productivity is to seek better natural fertility and lesser weed presence in newly cleared areas.

The smallholders' move towards extensification rather than intensification (Baudron et al. 2012) **is the very basis of the deforestation mechanism we observe in the ZILMP area.**

This is the case for instance in the Mocubela district, all around the GNR, southeast of Alto-Molocué districts or others places where there is forest.

Land-intensification is observed only in densely populated areas where forestland reserve is small. Thus, in Alto-Molocué for instance, we can observe contiguous plots, with shorter fallows, intensive exploitation of lowlands and the appearance of banana blocks (in lowland borders). Those adaptations help to increase the number of crop cycles throughout the agricultural year and to fully exploit the topography. The photos (Figure 38 to Figure 40) below show increasing land-intensification.

Figure 38: Newly cleared land in low-density area, planted in maize, north of Gilé. Land-extensive production

Figure 39: Exploitation of the topography: lowland rice cultivation, land on the slopes with several cycles (cassava, maize, peas...)

Figure 40: Very densely populated area: contiguous plots, strong diminution of fallow and presence of bananas in the landscape

According to us, this situation is likely to improve overall labor productivity but do not offset the downward trend in fertility. This is the reason why we can even observe exploitation of very steep slopes in land-constrained areas around Ilé.

Figure 41: Intensive exploitation of natural resources; due to high-population density around Ilé, even very steep slopes are cleared

Smallholders need increased sources of revenues from agriculture (whether it is from food or cash crops or from others activities) that could be intensified through better access to labor or external inputs. Otherwise, we can forecast future deforestation where forests remains and migrations from areas where forests have already disappeared.

1.2.3. Trade in food & cash crops in the ZILMP area

This section aims to analyze agricultural trade in the ZILMP area in order to see where opportunities exist to increase smallholders' revenue.

Based on surveys conducted in Gilé area, the main commercial options are those presented in the following table.

Table 28: Commercialization of different crops around Gilé. Adapted from (Lamarre 2015b)

	Cashew	Sesame	Cassava	Peanut	Cowpea	Maize	Pigeon pea	Rice	Yam
Part of the harvest sold (average estimate)	95%	100%	50%	27%	55%	37%	32%	10%	20%
Local yields (kg/ha)	1,5 - 12 (kg/tree)	150 - 500	600 - 1200	150 - 450	150 - 350	350 - 800	80 - 200	450 - 650	500 - 800
Price MZN per kg during the sale period	10 - 15	30 - 35	5 - 7	10 - 15	8 - 10	4 - 6	8 - 10	10 - 12	3 - 4
Equivalent USD / t	330 - 500	1 000 - 1 200	166 - 233	330 - 550	266 - 330	133 - 200	266 - 330	330 - 400	100 - 133
Sales period	Nov – Dec	July	Oct – Nov	Apr – May	June – July	June – July	Sept- Oct	July	July

Household inquiries conducted by *Agrisud International* and *Etc Terra* show that smallholdings in the area are based on a diverse and relatively balanced system, generating value both from food crop (*cassava-peanut-maize)* and from cash crops (*cashew-sesame)* (Figure 42). No production represents more than 20% of the gross value.

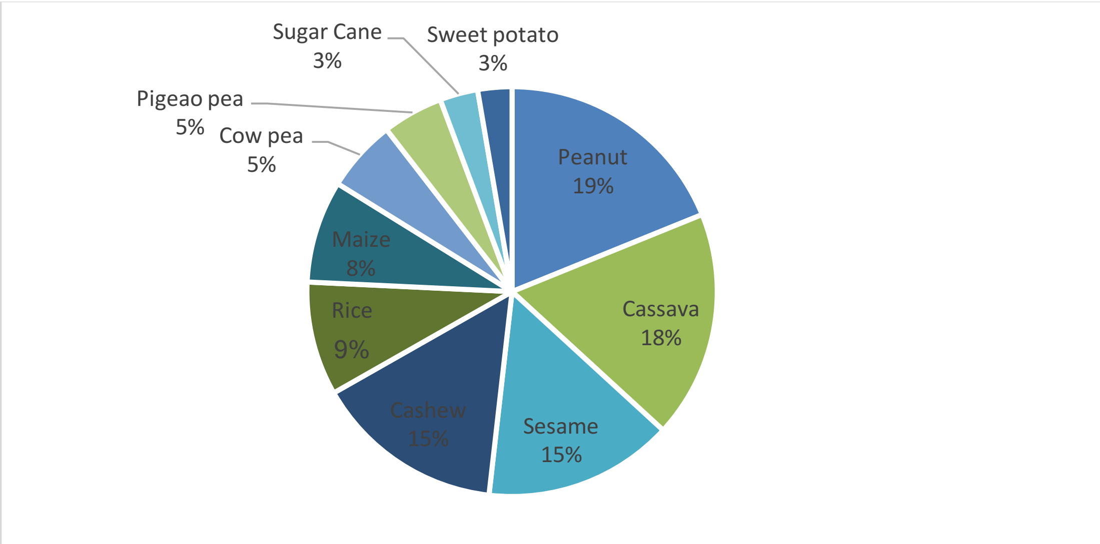


Figure 42: Gross annual smallholders revenue in meticais. Source: Agrisud & Etc Terra

However, cashew and sesame generates more than 50% of net household revenue, thereby standing as the economic engine of the area (Figure 43).

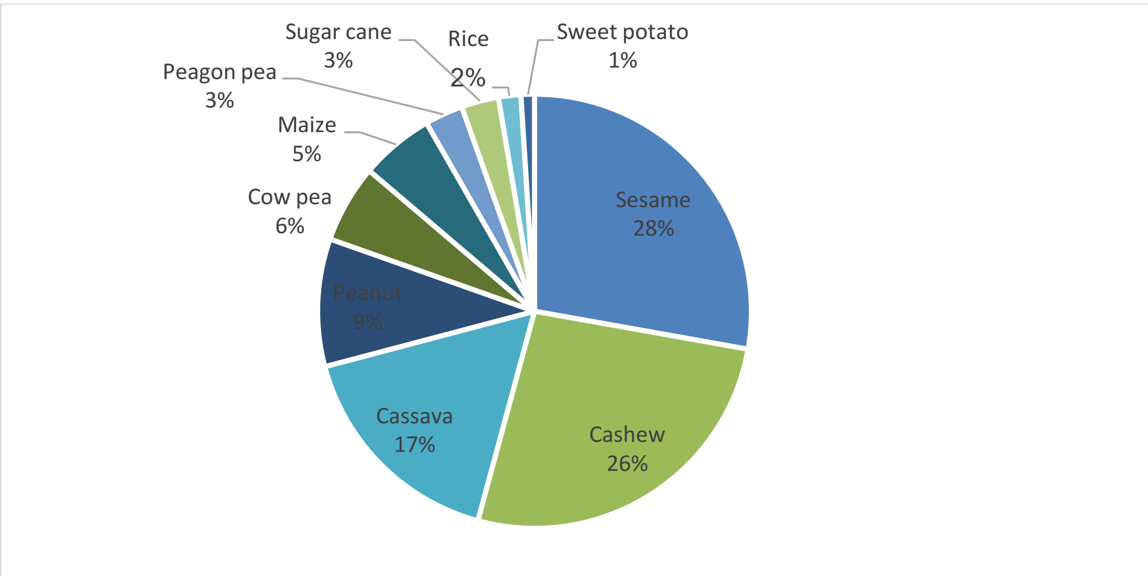


Figure 43: Net annual smallholders revenue in meticais. Source: Agrisud & Etc Terra

1. Food crops trading

The part of food crops that is not auto-consumed is sold on local market. Some surplus can reach the district capital. Buyers are mainly state workers who do not cultivate. There is very little local industrial processing. Most of the processing is done in artisanal mills to transform cassava chips and maize flour *(xima* production).

There is very little food being exported out of the districts for consumption, although an important demand exist in the south of the country, especially in Maputo. Nampula region is an important and well-structured supply basin for maize for Maputo, as shown by the small price difference between Nampula and Maputo (Figure 44). Besides, Maputo can always import maize from South-Africa (SAFEX in the figure below). Therefore, competition is already significant at national-scale: it would be very difficult for the ZILMP to enter this market, being a remote area facing high cost for collection, transaction and marketing.

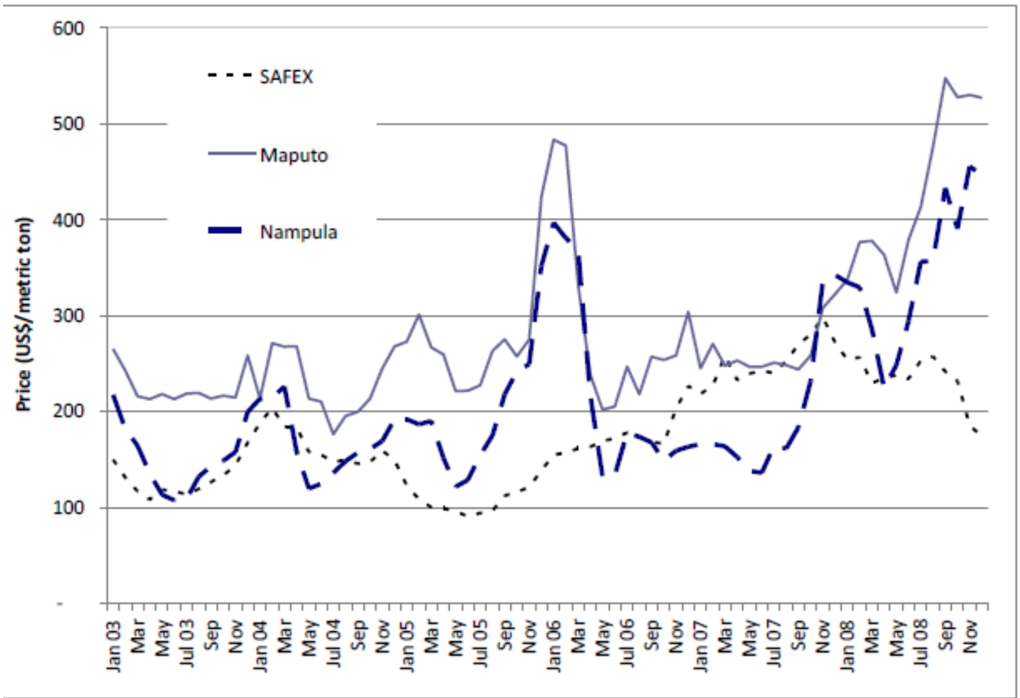


Figure 44: White maize prices in Maputo, Nampula and Safex, USD/ton. Source: FAO and SIMA

There is neither industrial demand for cassava nor maize. One of the rare exceptions is *Cerveja de Moçambique* for its cassava-based beer *Impala*, but the farm gate prices are very low compared to the prices to local consumers in the project area (1 - 3 MZN per kg vs. 5 – 7 MZN per kg) [6]. **Therefore, we do not really see opportunities for increased income in the ZILMP via an increase of the sale volume of maize.**

[6] http://www.jornalnoticias.co.mz/index.php/economia/31854-producao-da-cerveja-impala-mandioca-eleva-renda-familiar-em-inhambane

Without any industrial or national demand, the local market is the only option for small holders. Prices on this market are volatile, which leads to low investment and minimum risk-taking by farmers. As shown on Figure 45, cassava, maize and wheat prices are highly linked, illustrating a strong substitutability between flours and limiting the possible farm gate price for producers.

In this context, opportunities are very limited to increase smallholders' revenues through an increased production or better marketing of food products.

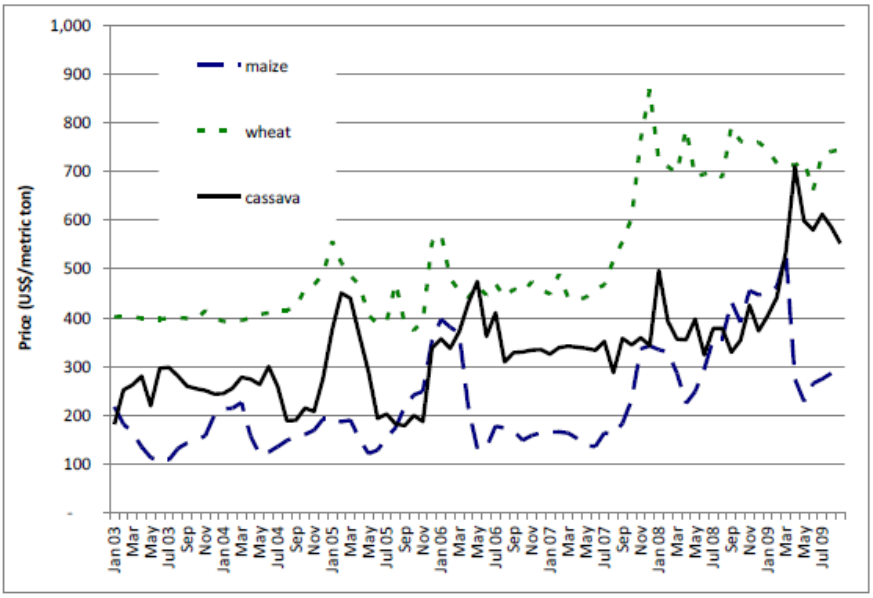


Figure 45: Nampula prices for maize grain, wheat flour and cassava flour in USD/t. Source: SIMA

2. Annual cash crops trading

Concerning annual cash crops, the production in Zambézia is shown in the figure below.

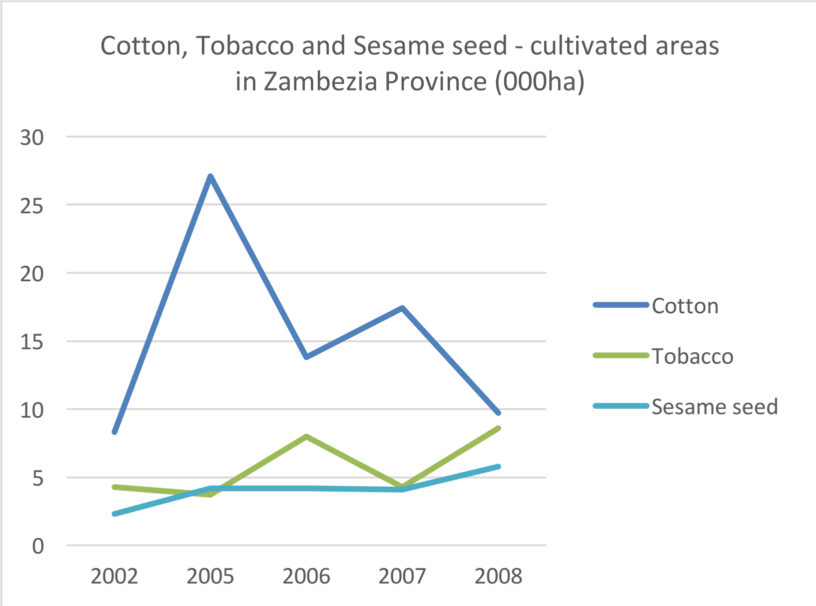


Figure 46: Cultivated area in cash crops in Zambézia. Source: Anuário de Estatísticas Agrarias

At the ZILMP level, we compiled data from SDAE in the following table.

Table 29: Annual cash crop production and surface in the ZILMP area. Source: SDAE, balanços agrícolas, 2015

Year 2015	Alto Molocué		Gilé		Ilé		Maganja Costa	
Cash Crops	Area (ha)	Prod (ton)	Area (ha)	Prod (ton)	Area (ha)	Prod (ton)	Area (ha)	Prod (ton)
Tobacco	1,925	2,888						
Sesame seed	272	245	7,826	7,140	37	20	765	765
Cotton	229	115	638	100	290			

Year 2015	Mocubela		Mulevala		Pebane	
Cash Crops	Area (ha)	Prod (ton)	Area (ha)	Prod (ton)	Area (ha)	Prod (ton)
Tobacco						
Sesame seed	725	290	1,398	964	651	651
Cotton			273	-		

Tobacco is only produced in Alto Molocué district (1,925 ha). Cotton is produced in Alto Molocué (229 ha), Gilé (638 ha), Ilé (290 ha) and Mulevala (273 ha), while sesame seeds are produced in all districts - Gilé being the main area of production (7 826 ha).

Table 30: Aggregated cash crop production and surface in the ZILMP area. Source: SDAE, balanços agrícolas, 2015

Cash Crops	Total prod (tons)	Total area (ha)
Sesame seed	10,075	11,674
Tobacco	2,888	1,925
Cotton	215	1,430

We can conclude that those cash crops have a very limited impact on deforestation: the areas are very limited in comparison of total agricultural land - estimated between 515,000 and 550,000 ha - and economic trends are not favorable for cotton and tobacco. Sesame seed is the only dynamic cash crop in the area. Sesame cultivation does not need fertile soils – this is why sesame is never placed in newly deforested areas.

3. Perennial cash crops trading: cashew, the quiet annuity

We only find cashew production in the South of the ZILMP area: districts of Gilé, Pebane, Mocubela, Mulevala and Maganja da Costa (see Table 31).

The production is very volatile because of climatic conditions. Farm gate prices are very low, contributing to the adoption of risk mitigation strategies and impeding long-term investments in these cultures, despite the presence of national extension programs (diffusion of cashew seedlings, treatments by INCAJU). **Therefore, cashew cultivation in the ZILMP area is very extensive: no real plantations, mainly old trees around house providing more shadow than RCN, little maintenance of orchards and hardly no treatments. Those factors make cashew be a real 'quiet annuity' for the smallholders.**

Table 31: Cashew production in Zambézia per district, in tons. Source: INCAJU

District	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014
Nicodala	6	53	6	13	4
Namacurra	554	452	97	361	33
Mocuba	662	1 076	115	1 812	468
Mag. Costa	1 011	1 571	374	510	725
Pebane	3 755	3 363	767	3 567	3 254
Gile	3 906	3 610	830	2 582	1 136
Ile	850	1 436	335	788	987
Namarroi	99	125	1	3,33	8
Alto Molocue	0	0	0	25,1	21
Mopeia	0	0	0	1,6	0,125
Quelimane	0	0	0	0,01	0,02
Murrumbala	0	0	0	0,05	0,185
Total	**10 843**	**11 686**	**2 525**	**7 707**	**6 435**

Farm gate are very low compared to international market: for instance, in December 2015, in the middle of the harvesting period in east Africa, RCN in Tanzania was twice (1200 USD/t) as expensive as in Mozambique (600 USD/t) (Figure 47), although buyers are the same, that is Indian and Vietnamese importers. **Therefore, there is a huge opportunity to increase smallholders' income with this commodity.**

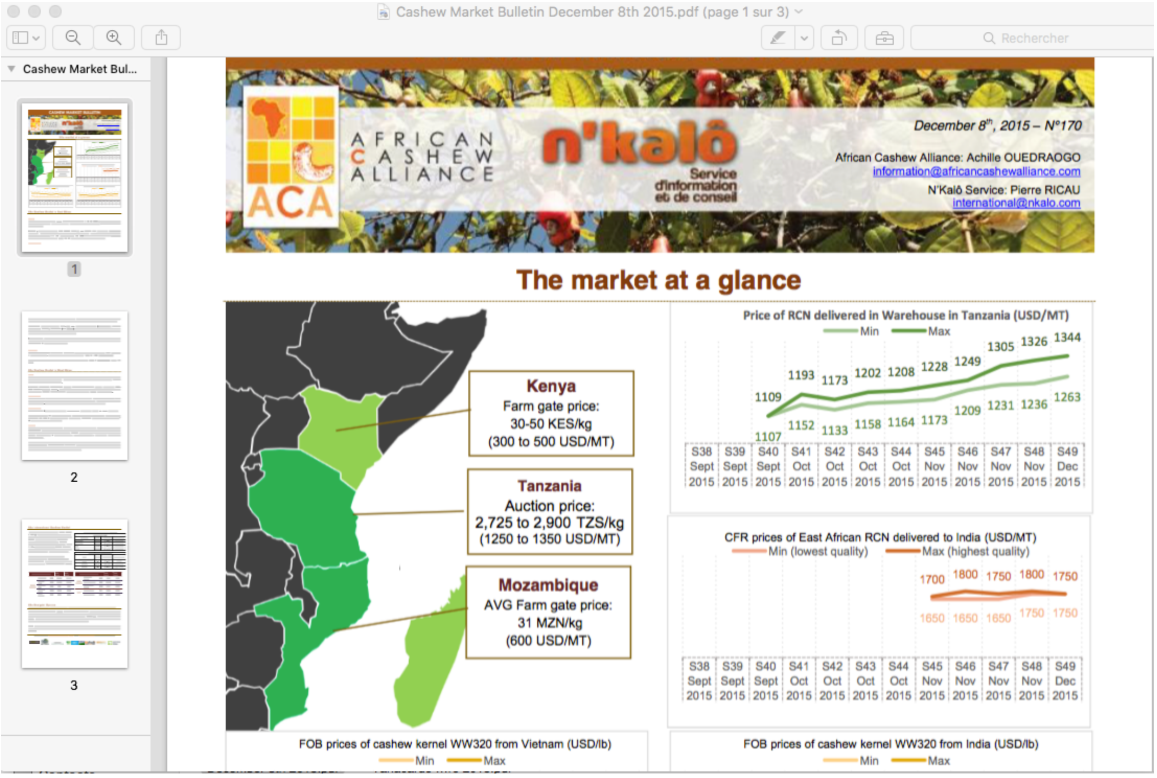


Figure 47: Comparison of RCN price in East Africa in December 2015. Source: Nkalo Market Information Service

2. Bioenergy production and consumption: charcoal & fuelwood

According to our surveys, in the ZILMP area, fuelwood for households is composed of **firewood in rural areas and of a mix of firewood and charcoal in urban areas,** depending on cities' neighborhoods. **Firewood collection is almost entirely related to "slash and burn" agriculture**. Only wood from tree cut for opening a field is used. If it doesn't come from fields, **firewood is constituted of deadwood harvested on woodlots or orchards near villages. Therefore, this consumption has no additional impact on forest cover, relatively to agriculture,** and is not considered as a cause of deforestation or forest degradation.

On the contrary, **charcoal is only partly produced from tree feeling for *machambas* opening. Most of the production is done outside of agricultural fields (between 80% to 92%, depending on districts -** Table 33**) causing additional deforestation or degradation**. This production is concentrated around cities where charcoal consumption exists.

To quantify deforestation or degradation caused by charcoal production and to understand its value chain - first step to address the cause of deforestation/degradation - a large survey was carried out over the seven districts on consumption and production centers (see Annex 4: Survey method for charcoal value chain analysis for details on the methodology). All results presented here come from this survey. The main objectives were (i) to estimate the quantity of charcoal production and its impact on forest, (ii) to identify the production basin where actions shall be undertaken on a priority basis and (iii) to assess the parts of the value chain where actions can serve as levers to lower impacts on forests.

2.1. Estimation of charcoal production location, intensity and impact on forest

As explained, the vast majority of charcoal is consumed in the urban centers of the 7 districts composing the program area. Most of urban households consume charcoal, but actual figure depends on the cities (Table 32). Estimates on consumption will help evaluating the quantity of charcoal delivered in, and so produced for, each city per year (Table 32).

In the ZILMP area, **Alto-Molocué is the main city in terms of number of inhabitants but also of proportion of charcoal consumers**. This city largely represents the main part of the consumption - and so, production - of the 7 districts (35% of the consumption). Proportions of consumers are also high in Ilé and Maganja da Costa (Table 32). This situation can be explained by the proximity of all those cities to the main road of the 7 districts connecting Quelimane - capital of the province - and Nampula, this proximity favoring the transport of goods like charcoal and extending supply basins. The situation in Maganja da Costa is currently changing as the bridge connecting the city to Quelimane caved in. Before this incident, charcoal production around Maganja was also supplying Quelimane but now, transport of charcoal around this city has been rearranged and has decreased. Charcoal is usually produced in a radius of 30 km around those small size cities (Table 33).

Table 32: Characterization of the charcoal consumption in the urban centers in the 7 districts of the program area

	Gilé	Pebane	Maganja da Costa	Alto Molocué	Ilé	Total
Number of inhabitants	21,969	22,535	13,438	37,437	15,570	110,949
Percentage of charcoal consumers in the city population	74%	63%	86%	93%	90%	
Mean number of bags consumed per month per households	2.8	2.6	2.6	2.4	2.7	
Equivalent in tons per year	3,707	3,684	3,036	7,634	3,363	21,424
Consumption of charcoal in t/year/household	1.5	1.6	1.7	1.3	1.4	

Constraints on producers explaining the location and the quantity of their productions are the following:

- **The availability of the resource**: in area where there is still a significant quantity of forests (Gilé and Maganja districts), competition for land use is low and producers have a free and easy access to wood resources. On the contrary, in Ilé and Alto Molocué districts, resources are becoming rare and competition for land use is rising. Thus, some charcoal makers have to pay to have access to woodlots and have fewer choices in tree species.
- **Production will be concentrated next to roads** (max 2 km in average) in order to facilitate transport to markets.
- Humid earth is necessary to assure higher yields. Hence production near rivers is interesting and production level decreases during dry season as less experienced producers stop this activity.
- **Few species are preferred for the production of charcoal** according to their size, abundance and combustion properties: *Brachystegia spiciformis* and *Julbernardia globiflora*. They are the main species found in the Miombo forest of the program area. During production, charcoal producers will therefore choose a place where those species are abundant and select only trees of interest (depending on the species and the size of the trees). **This selection of tree species makes charcoal production be rather a cause of degradation than of deforestation,** because no entire plots are cut during production (see following photos).
- Trees will be selected on a small area around the kiln to ease the work of wood transport, reinforcing the argument according to which charcoal production rather is a cause of degradation. The size of the area impacted is, on average, 25 m around the kiln. However, if too many producers are working next to each other, the activity can lead to deforestation.
- **Usually, producers choose to make smaller kilns but more frequently to ensure regular incomes.** The key phases of the production are the construction with appropriate earth and the surveillance - no holes should appear on the earth around the kiln - to ensure good yields (this issue will be detailed in the following section).

Figure 48: Photos of kilns construction in the ZILMP area (A. Trégourès)

According to survey results, **charcoal producers make, on average, 21 kilns of 3 to 6 m long every year** (Table 33). Those results vary depending on the district and on the proximity of cities. Yields of traditional kilns are usually low, about 20% in the area (Falcão 2008). They usually lead to a production of 1.6 bags of 48 kg per m^3. Given this average data on production and total consumption in each city, it is possible to estimate that there is usually between **500 to 1,000 charcoal producers at the beginning of the value chain around each urban center, except in Pebane** where this number is smaller (Table 33). Hence, according to usual practices (trees of interest are selected on a 25 m radius circle around the kiln), at the program area level, **charcoal production impacts, on average, a total of 10,770 ha in the Miombo forest** (Table 33). **This impact is mostly degradation, because producers select species of interest, but in some cases, it can be deforestation if kilns are made on areas close to producers' fields or if producers work close to each other.** It is difficult to discriminate part of deforestation and degradation on the areas impacted but this can be compared to annual areas of deforestation in each supply basin. Those results are presented hereafter.

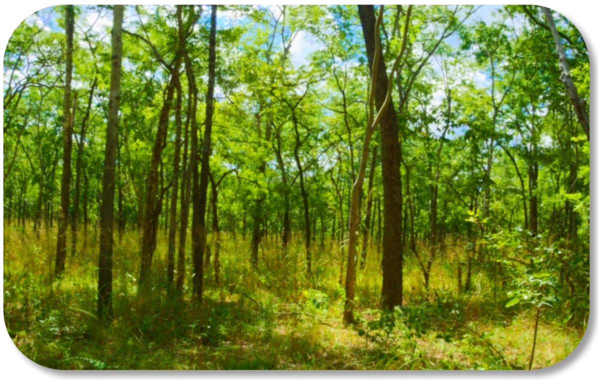


Figure 49: Photos of 'intact' natural Miombo forest above and of Miombo forest after degradation for charcoal production below (A. Trégourès)

Table 33: Characterization of the charcoal production in the supply basins of urban centers in the 7 districts of the program area (preliminary results for Gilé, Maganja and Pebane)

Urban centers sampled in the 7 districts	Gilé	Pebane - from the Miombo forest	Pebane - from mangroves	Maganja da Costa	Alto Molocué	Ilé	Average
Radius of the supply basin in km	22	17	3	17	29	17	22
Estimates of the number of producers working in the supply basin	580	185	98	401	930	729	487
Mean number of kilns per producer per month	19	18	29	11	29	22	21
Mean length of kilns in m	3.3	6.2	5.6	5.5	5.2	4.3	5.4
Mean percentage of kilns done with trees from slash and burn agriculture per producer per month	12%	10%	1%	8%	17%	8%	10%
Equivalent of the area of forest impacted (degradation or deforestation) in ha/year	2,131	601	544	747	4,382	2,909	1,886

Supply basins of each city were delimitated with an analysis based on the distances to several factors impacting the choice of the location for charcoal production, identified during the survey: distance to resources (forests), distance to roads and distance to rivers.

Maximum distance to market (usually near the city center) was assessed thanks to producers' statements. A map of the different supply basins is presented below.

On this basis, deforestation due to a mix of agricultural and charcoal productions in those areas was estimated (Table 34). The main supply basin in size and production is logically the one around Alto-Molocué. Indeed, because the level of consumption is the highest while the resource is relatively rare around this city where deforestation was severe during the 90s, producers now need to look for trees up to 30 km from the city. Basins of Gilé, Maganja and Ilé are similar in size and production, which can be explained by their distance to main roads (Ilé) and to high forest cover (Gilé and Maganja).

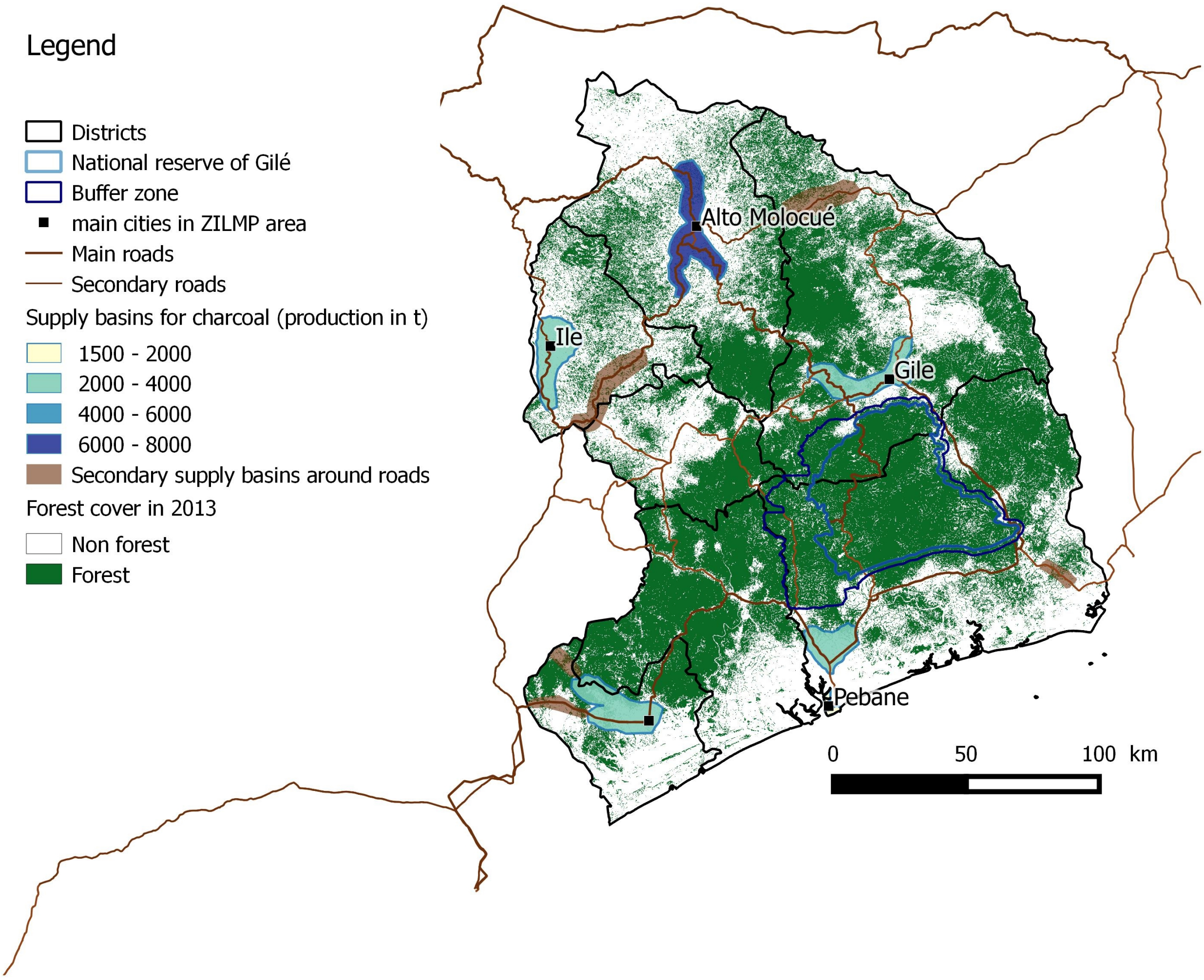


Figure 50: Map of supply basin for charcoal around main cities of the program areas and on main transportation axes

Deforestation rates around main cities are largely higher than in other areas of districts (Table 34) because of a higher pressure for agriculture and additional pressure for charcoal during the recent period. High deforestation rates around cities during the periods 1990 and 2000 (Table 34) are due to strong population migrations after civil war towards urban areas, leading to high expansion of agriculture around. Between 2010 and 2013, 3,171 ha were annually deforested in cities supply basins, to be compared to the yearly 10,770 ha of forest impacted by charcoal production. Yet, 10% of additional production is realized with wood from "slash and burn" fields, corresponding to an area of about 1,000 ha. This impact of charcoal production is therefore already accounted for in the analysis of deforestation areas – and so, emissions - in the supply basins. This deforestation can be attributed to agriculture and charcoal as a by-product. In other words, the impact of charcoal production is degradation that comes in addition to deforestation due to agriculture.

Emissions related to charcoal production were calculated (see Annex 5: Method for the calculation of emissions due to charcoal production). Depending on the default value used for biomass expansion factor, **it can be approximately estimated that emissions due to charcoal production in supply basins are between 288,343 tCO_2eq/year and 876,274 tCO_2eq/year, to be compared to the 3.3 $MtCO_2eq$/year of emissions due deforestation in the overall program area.** Therefore, depending on the results, **degradation due to charcoal production would represent a part of 8% to 20% of program total emissions due to deforestation.**

According to the FCPF MF indicator 3.3 (FCPF 2013), if degradation represents more than 10% of the level of emissions due to deforestation, they must be taken into account in the program REL. Hence, it is necessary to estimate with accuracy a specific program biomass expansion factor in order to decide if degradation should be included in the program REL. This can be done by measuring all tree volume during constructions of kilns, which requires a specific survey.

Table 34: Total deforestation in the supply basins in comparison to deforestation rate in the program area

Data on areas		Program area		Supply basins	
		Areas in ha	Annual deforestation rate	Areas in ha	Annual deforestation rate
Total area		3,865,062		173,303	
Forest cover	**2013**	1,983,784		38,244	
Historical deforestation	**2010-2013**	66,777	-0.86%	3,171	-2.05%
	2005-2010	54,637	-0.61%	3,525	-1.93%
	2000-2005	64,838	-0.55%	5,393	-2.04%
	1990-2000	123,541	-0.60%	9,771	-1.95%
Mangroves		53,348		252	
Other areas		1,518,137		112,947	

2.2. Characterization of the value chain

According to the survey results, charcoal value chain in ZILMP area is organized around several actors:

- *Producers*:
    - Charcoal production can be their main or their secondary economic activity (83% of charcoal producers also have another economic activity, often, if not always, agriculture). If it is the main activity, they work 10 months a year for charcoal production (for a production of 11.8 t/yr in average) and if not, they work 8 months a year (for a production of 8.4 t/yr in average). For 17% of producers, charcoal production is their unique economic activity.
    - They can directly sell their charcoal to different market places or they can sell it to carriers that come to the production area. The proportion of charcoal producers that make the production and transport to market is relatively high, revealing the low level of organization of the value chain.
- *Intermediaries or carriers*: they buy charcoal directly to producers at the production zone and they provide for transport to resell charcoal to retailers at market place.
- *Retailers*: they buy big bags of charcoal to producers or intermediaries and resell them directly in big bags or on small daily portion. They are in direct link with consumers. Consumers live in city centers, those at the periphery having easier access to firewood.

Figure 51: Pictures of small carriers with bicycle and of retailers on markets (A. Trégourès)

Prices vary depending on seasons during the years because of variations in quantity of available charcoal (Figure 52). Indeed, only charcoal producers for whom this is the main activity work almost the whole years. Others stop charcoal production at the end of the dry season and during period of intense agricultural works (rainy season).

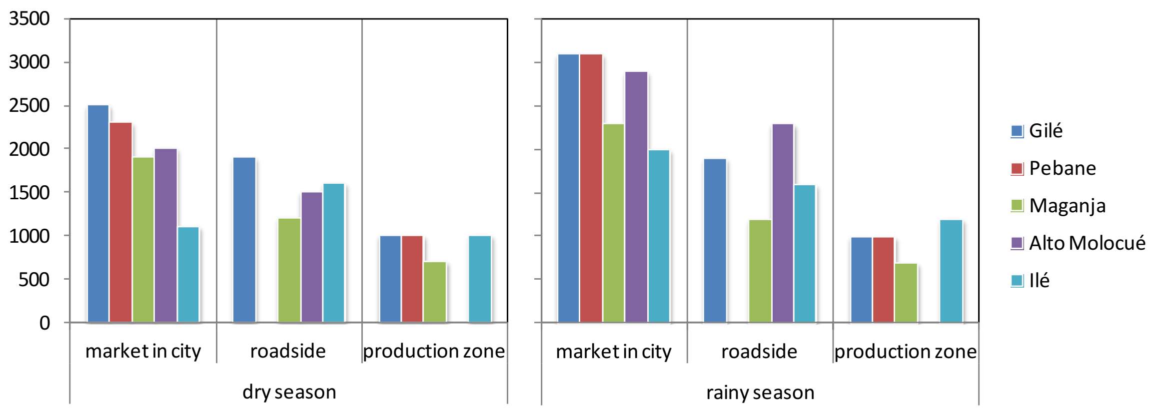


Figure 52: Variation of the prices of charcoal depending on the period of the year and on the place of sale – prices in meticais[7] per ton of charcoal

From knowledge of charcoal prices and estimates on production and transport costs, an assessment of the revenues for different actors was done. It is presented in the following table. Small intermediaries are the one generating the smallest benefits. For producers, it seems more interesting to sell in cities but the transports are time consuming, infringing on agricultural works or charcoal production increase.

Table 35: Estimation of revenues from charcoal sales for different actors of the value chain

Actors		Revenues (in meticais/month)
Producer	Producer - roadside or production zone	1,300 – 1,800
	Producer - market in city	1,200 – 2,000
Intermediary	Small with bicycle	600 -800
	Large with car	2,300
Retailer		1,440

Following statements from present results reveal that **the charcoal value chain in the ZILMP area has a low level of organization** due to the relative small size of cities in the program areas:

- Few producers have made charcoal production their unique economic activity. This activity is to improve incomes from agriculture and to generate revenues during outside harvesting period.
- There are few intermediaries and they are usually small without motorized vehicle.
- The size of supply basin is relatively small (in area) for high number of producers because of the absence of motorized vehicles.

[7] 1000 MZN = 21 USD

Actions to address the issue of charcoal production will therefore focus on producers and consumers. **As the majority of producers have also another economic activity, they are settled in their area of production. Consequently, it is easier to identify them and to work with them on the adoption of sustainable practices.**

3. Forestry

3.1. Context of logging in Zambézia and the ZILMP area

Logging in Mozambique can occur in two types of land uses that obey to different regulations:

- Concessions: lands are allocated to companies for 50 years. To obtain the administrative authorization to exploit those concessions, a management plan is required. Companies also need to be in possession of timber processing facilities. They are prohibited from exporting unprocessed log of first class species[8].
- Simple licenses: they consist of a 5 years permit that limit the maximal harvesting amount to 500 m^3 per year, on an area that should not exceed 10 000 ha. They are available for Mozambican citizens only and require simplified management plan.
- Forest concessions were introduced in 1999 to guarantee the sustainability of exploitations. Although they were, initially, supposed to replace simple licenses, the latter still exist: as they imply fewer responsibilities and represent a higher part of production (about two third of the authorized volume, according to A. Sitoe, Salomão, and Wertz-Kanounnikoff (2012)), they still are more appealing.

The main legal instruments that define forest exploitation in Mozambique are the following (Falcão, Bila, and Remane 2015):

- The Forestry and Wildlife Regulations (2002), which recognizes forest concessions as a new regime of land use to promote sustainability.
- Conservation law (2014).
- Environment law (1997).
- Policy and strategy for the development of the Forestry and Wildlife sector (1997).
- The moratorium on *pau-ferro* (*Schwartzia madagariensis*) exploitation and on the deliverance of new forest concession and simple licenses (1st of January 2016).

In Zambézia, in 2015, 31% and 21% of program area was ruled, respectively, by operational concessions and simple licenses (Figure 53). In 2011, operational concessions and simple licenses represented, respectively, 15% and 4% of the program area showing an important increase in area under forest exploitation in the period. The percentage of forest covered by simple licenses is inferior to the percentage of the ZILMP area covered by simple licenses, we can conclude that licenses are surprisingly attributed in area where there is low forest cover.

[8] 22 species of which Jambire (*Millettia stuhlmannii*), Chanfutta (*Afzelia quazensis*), Umbila (*Pterocarpus angolensis*) and Pau-Ferro (*Swartzia madagascariensis*)

In Zambézia, 31% of delimitated concessions are currently operational. The final approval for the attribution of the remaining 69%, which is still being analyzed by the administration, will depend *inter alia* on the approval of the management plans. Concerning simple licenses, currently 58% are operational and the status of the other is pending.

In order to assess the share of deforestation that occurs inside concessions and simple licenses areas, data were extracted from deforestations maps (Table 36). They were analyzed in light of the past deforestation data from the 2010 – 2013 period and of the 2011 delimitations of concession and simple licenses areas.

Without any restriction on land use by households in logging concessions, it is not possible to differentiate deforestation that would have been caused, exclusively, by logging or by "slash and burn" agriculture. However, to the contrary of agricultural practices, it is very likely that logging leads to degradation rather than deforestation: exploitation pressure being concentrated on few species only (Figure 54)**.** Whereas deforestation rates in concession areas are similar to those of the overall program area (Table 36), they are higher in simple licenses areas, highly above the program area rate: 0.86 %/yr. This may be explained by fast attribution of lands, leading to a rapid exploitation of the available timber, with lower selection of tree species (Table 36). Given this, we can infer that logging concessions or licenses do not mitigate deforestation dynamics.

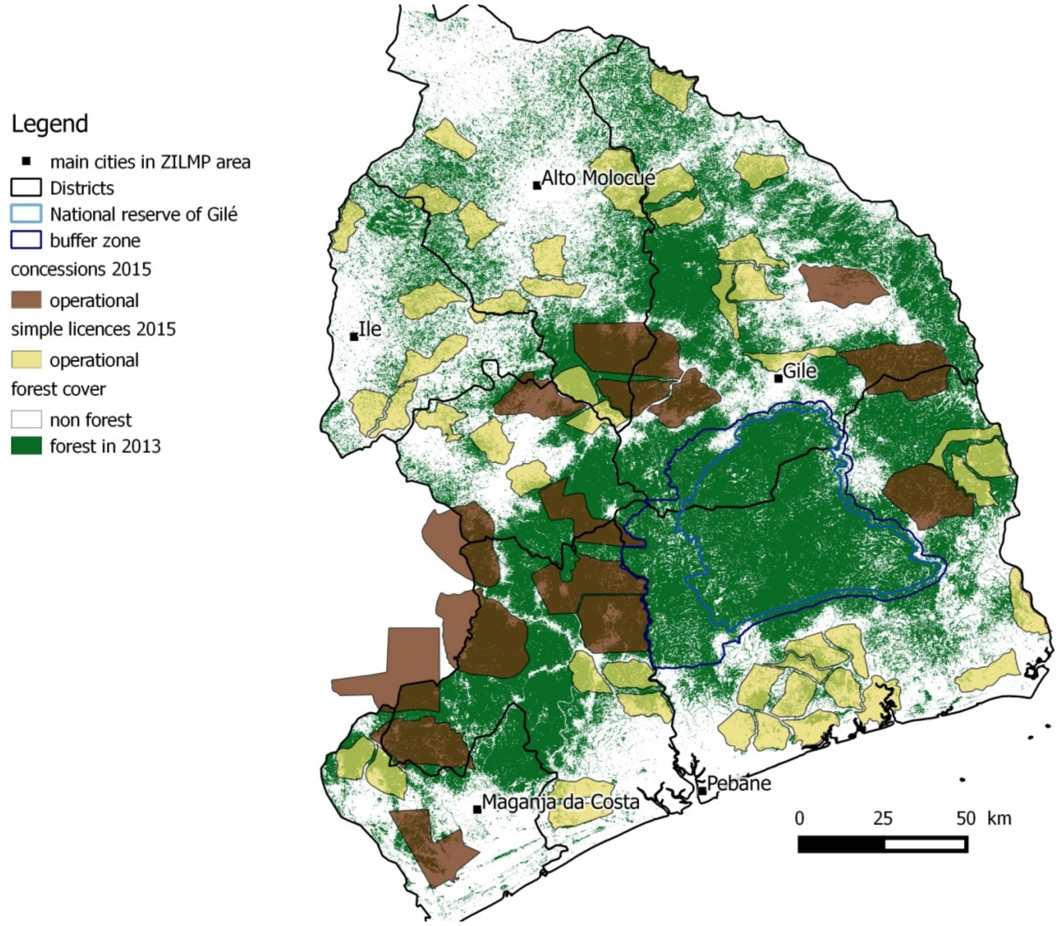


Figure 53: Map of operational forest concessions and simple licenses in the ZILMP area in 2015 (Source: SPFFB Zambézia, retreatment by Etc Terra)

Table 36: Proportion of forests in the program area that was under concession or simple license status in 2011 and in 2015 and corresponding deforestation rate during the recent period 2010-2013

Land cover classes	ZILMP	2011		2015	
		Concessions	Simple licenses	Concessions	Simple licenses
Total area	3,865,062	594,925	157,794	1,208,748	799,292
Proportion of the ZILMP area	100%	15%	4%	31%	21%
Forest cover in 2013	1,983,784	461,045	82,829	766,025	348,119
Proportion of the forest	100%	23%	4%	39%	18%
Historical deforestation rate between 2010-2013	-0.86%	-0.39%	-1.12%	-1.09%	-1.75%

The main species exploited are presented in Figure 54; they correspond to data from Cabo Delgado province but the context is similar in Zambézia province.

In Mozambique, and in Zambézia province especially, current practices are based on short cutting cycles that jeopardize logging sustainability: although it is acknowledged that a 30 years rotation would be necessary in the Miombo forest to ensure regeneration (Mackenzie and Ribiero 2009), management plans are usually based on a 20 years rotation, or less (often, 5 to 10 years rotation). EIA (2014) estimates that, with a linear evolution of the 8% exploitation growth rate, the exploited species stocks would be exhausted within 15 years.

Official data estimate exploitation volumes in Zambézia (German and Wertz-Kanounnikoff 2012; Mackenzie and Ribiero 2009):

- In 2009, in Zambézia, licensed volumes were 18 046 m^3 for concession areas and 22 345 m^3 for simple license areas. That was the second highest production of Mozambique, just after Sofala province (source: DNFT as reported by German and Wertz-Kanounnikoff 2012).
- In 2007, 14 simple licenses and 99 concessions licenses were issued in Zambézia province for a total volume of 36 693 m^3, close to the 2009 amount (Mackenzie and Ribiero 2009).

Exported quantities are higher than licensed quantities: most exports are illegal and, therefore, excluded from official reports – as explained hereafter (Mackenzie 2006; Mackenzie and Ribiero 2009). Hence, estimates given by official data should be far below timber exploitation real rates.

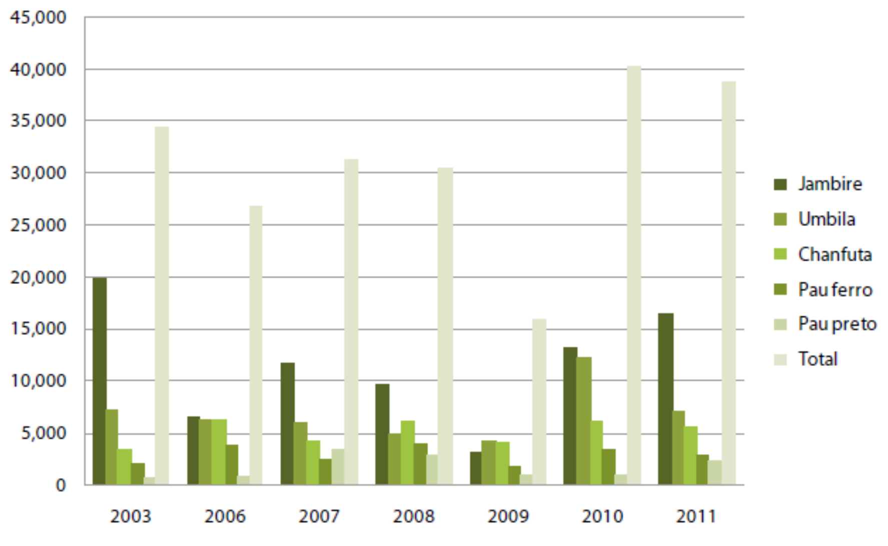


Figure 54: Species cut in Cabo Delgado province of Mozambique from 2003 to 2011 (From Ekamn, Wenbin, and Langa E. 2013)

3.2. Significance of Illegality in the logging sector

Today, 50% of the quantities of timber shipped out of Zambézia is believed to be illegal (Ekamn, Wenbin, and Langa E. 2013; Mackenzie 2006; Mackenzie and Ribiero 2009). In

Mozambique, this share could reach 76% to 93% of timber production (EIA 2014). Most of the wood (about 80%) is exported towards China (Ekamn, Wenbin, and Langa E. 2013; Mackenzie and Ribiero 2009). Yet, Mozambican reports of exportations towards China do not correspond to the Chinese importation level from Mozambique (Figure 56), giving an indicator of illegal exportation.

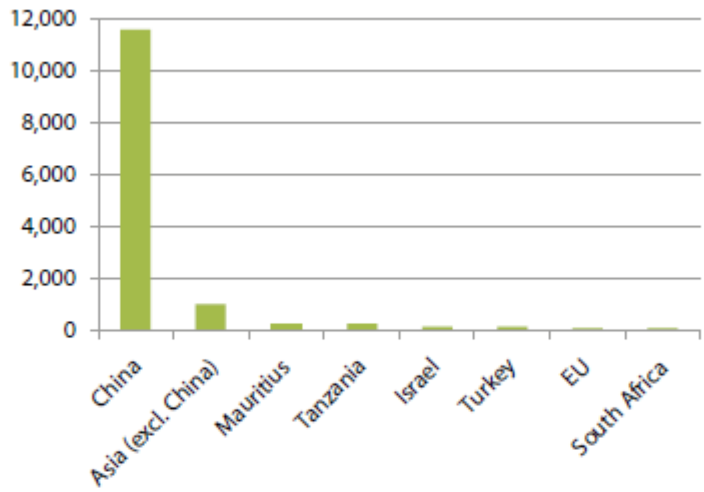


Figure 55: Exports of wood from Cabo Delgado province of Mozambique by destination during the year 2010 in m^3 (From (Ekamn, Wenbin, and Langa E. 2013)

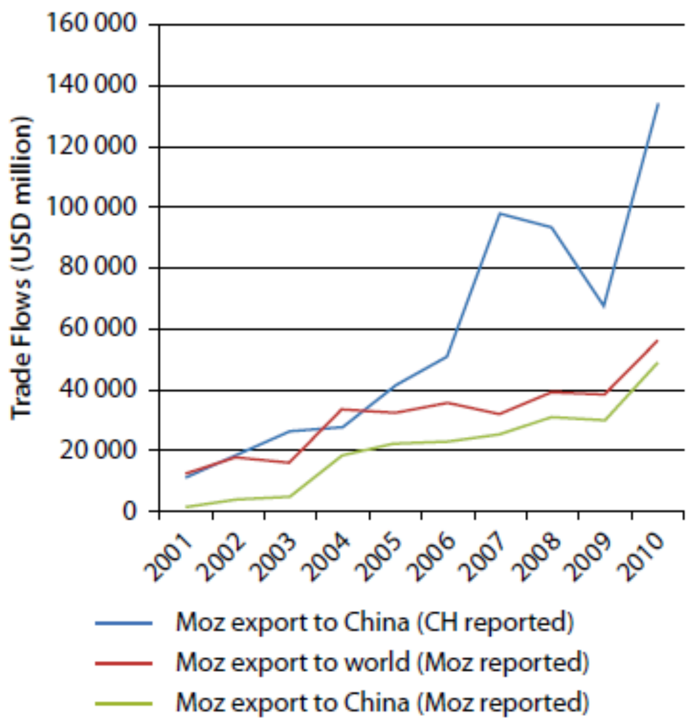


Figure 56: Value of timber exports from Mozambique (Moz) to China (CH) and to the world as reported by the respective countries (Source: UN COMTRADE as presented in (German and Wertz-Kanounnikoff 2012))

Illegality lies in different practices, from illegal harvest that do not respect management plans (see Figure 57) to violation of labor laws, violation of transport laws and illegal exports of unprocessed timber for first class species (Ekamn, Wenbin, and Langa E. 2013; Mackenzie 2006; Wertz-Kanounnikoff S., Falcão M.P., and Putzl L. 2013). Again, whereas Mozambican authorities declare that 20% of exportations are composed of unprocessed logs, in accordance with the law, China declares 75% of unprocessed log imports in 2010, underlying illegal practices in timber processing (German and Wertz-Kanounnikoff 2012; Ekamn, Wenbin, and Langa E. 2013). A study of Falcão, Bila, and Remane (2015) shows that companies that export unprocessed logs can reach a 2,430 USD benefit per container, against 530 USD per container for legal wood, because (i) cost is not related to processing and (ii) logs are sold at a higher price in China. According to (EIA 2014), uncollected taxes related to illegal logging accounted for approximately 146 millions USD between 2007 and 2012 between 3 and 6 USD per log are usually paid to the loggers hired in villages.

Widespread illegality in logging sector is enhanced by weak law enforcement, as illustrated by the limited number of fines - 177 in Zambézia province in 2007 - compared to the extent of the illegality phenomenon, and a high degree of corruption along the value chain (Mackenzie 2006; Mackenzie and Ribiero 2009). In Zambézia province, the main agents of logging are Mozambican and Chinese companies (German and Wertz-Kanounnikoff 2012; Mackenzie and Ribiero 2009).

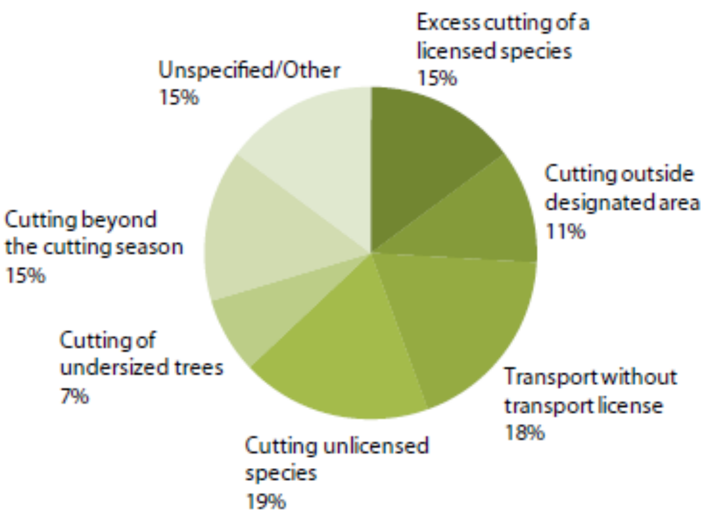


Figure 57: Reported fines by the Mozambican authorities illustrating the types of violations committed by simple license holders (from Ekamn, Wenbin, and Langa E. 2013)

Table 37: National origin of concession holders in Zambézia province during the year 2008 (From Mackenzie and Ribiero 2009)

	Mozambican	Asian	Asian-Mozambican Joint-Venture	American	European	TOTAL
Operators	9	5	7	1	3	**25**
Concessions	11	8	7	1	5	**32**
Area (ha)	474,731	294,334	176,800[10]	21,278	235,432	**1,202,575**
Avg concession area (ha)	43,157	36,791	25,257	21,278	47,086	**37,580**

3.3. Estimations of emissions due to forest degradation by legal and illegal logging

As explained before, forest exploitation is a driver of forest degradation rather than of deforestation. It may be interesting to compare the share of emissions due to forest exploitation with global emissions due to deforestation in the overall program area. Estimates can be based on exported quantities from Zambézia and on several hypotheses about exploitation methods and impacts. To do so, we estimated the following factors:

- **Emissions from the dead wood pool** composed of residual from stand damage, branches and trimmings left in soil after logging. Carbon from this pool is gradually emitted while the biomass is degrading. In this pool, carbon can be estimated with factors detailed in literature and correlated to carbon stocks in merchantable quantities. However, the lack of data on forest exploitation in Mozambique prevented us from following this methodology. Instead, dead wood pool carbon stocks were considered as a difference between carbon stocks in the estimated total biomass and merchantable biomass (i.e. biomass in logs). The decay rate was considered similar to the one recommended by IPCC for belowground biomass (i.e. 10%/yr).
    - **Total biomass** is estimated with expansion factors for conversion of wood removals (BCEF) as recommended by the (IPCC 2006).
    - **Merchantable biomass** is estimated with a relation between wood density and exploited volume as recommended by IPPC. For wood density, an average for the main exploited species was used.

- **Emissions from long term harvested wood products** (ltHWP), composed of emissions from the decomposition or burning of processing residues and from the oxidation of long-lived wood products. The first component was conservatively set to zero wood, since it is mostly not processed in Mozambique and few relevant data are available about processing techniques. The second component was estimated as precious wood from forest exploitation in Mozambique, as it is mostly used to form planks and pieces of furniture. According to VM0011 methodology, fraction of carbon remaining in ltHWP can be estimated with the following equation (k being the rate of oxidation of ltHWP and t the elapsed time since wood processing):

Equation 6:

$$F_{ltHWP_{remain},t} = e^{-k_{ltHWP}t}$$

- **Removals from regrowth after selective logging** have to be assessed with annual growth rates. However, since it is not possible to assess the areas that have actually been impacted by selective logging, the total biomass would be retrieved with a delay considered in a 5% regrowth rate - which means that 20 years would be necessary to ensure post-logging regeneration (Mackenzie and Ribiero 2009).

Data and hypothesis are summarized in Table 38.

The result is an estimation of 0.04 MtCO$_2$eq over a period of 10 years (Table 39**). This represents a proportion of 1.2% of emissions due to deforestation (3.3 MtCO$_2$eq/yr), as assessed by the baseline of the ER program established in the present study.**

This proportion is relatively low but, when added to emissions due to charcoal production (see Estimation of charcoal production location, intensity and impact on forest), global emissions from degradation exceed 10%: they are significant. Therefore, according to criterion 3.3 of FCPF MF, degradation should be included in the program REL. An overview of emissions due to various causes of deforestation is presented in the *Analysis of drivers of deforestation and forest degradation* section.

Table 38: Data and hypothesis for the calculation of emissions and removals from degradation due to selective logging in the program area

Factors and pools		Data	Units	Sources
Exploitation data				
Licensed volume exploited in Zambézia	Concessions	18,046	m^3	DNFT - German and Wertz-Kanounnikoff, 2012
	Simple license	22,345	m^3	
Part in the program area	50%	8,939	m^3	Data on concessions
	48%	10,796	m^3	
Total with illegal exploitation		78,938	m^3	
Total tree biomass				
BCEF		0.89	tdm/m^3	IPCC, 2006
Root-to-shoot ratio		0.28		
Bark fraction		0.1		
Carbon fraction		0.47	tC/tdm	
Equivalent total AGB and BGB biomass		45,567	tC	
Carbon in merchantable volume				
Wood density		0.79	tdm/m^3	IPCC, 2006
Carbon fraction		0.47	tC/tdm	
Total merchantable biomass		29,310	tC	
Emissions dead wood pool				
Carbon in residual stand damage and branches and trimmings		-	tC	
Difference between merchantable biomass and total biomass		16,258	tC	
Annual decay		0.1		
Long term harvested wood product				
Stocks in residues from processing		-		
Oxidation rate		0.023		VM0011, VCS
Regrowth after selective logging				
Annual rate		0.05		

Table 39: Results of the estimation of emissions from selective logging (legal and illegal) over 10 years in the program area

	Emissions in tCO_2eq				
Year	Emission from non merchantable volume	Emission from processing	Emission from merchantable volume - ltHWP	Removals from regrowth	Total emissions
1	5,961	0	2,444	- 8,354	51
2	11,922	0	7,275	- 16,708	2,489
3	17,883	0	14,441	- 25,062	7,262
4	23,845	0	23,887	- 33,416	14,315
5	29,806	0	35,561	- 41,770	23,597
6	35,767	0	49,414	- 50,124	35,057
7	41,728	0	65,396	- 58,478	48,646
8	47,689	0	83,457	- 66,832	64,314
9	53,650	0	103,552	- 75,186	82,016
10	59,611	0	125,633	- 83,540	101,705
Average	**32,786**	**-**	**51,106**	**- 45,947**	**37,945**

4. Others drivers of deforestation

4.1. Mining

There are two mineral commodities of interest within the ZILMP area: **Tantalum and Heavy Sands.**

The area between the N1 Road and the GNR is very promising for tantalum. **Four important deposits** (see Figure 58) **have been kwown** for a very long time in:

- **Muiane** (Gilé district). *Tantalum Mineração e Prospecção Limitada* (a subsidiary of the Canadian Pacific Wildcat Resources Ltd.) owns a 1,660 ha mining concession, currently under exploitation.
- **Murrua** (Mulevala district). The 1,080 ha mining concession is owned by *Highland African Mining Company Limitada* (a subsidiary of the UK-Based Noventa). It is currently under exploitation.
- **Maropine** (Mulevala district). The 11,280 ha mining concession is also owned by *Highland African Mining Company Limitada*. Exploitation stopped in 2014, but the processing plant is still operating with the mineral coming from the Murrua concession.
- **Mutala** (Alto-Molocué district). There are several mining concessions there, including one that is owned by *Highland African Mining Company Limitada.* The deposit was exploited until the mid-80s and might be again in the coming years.

Those sites produce the entire Mozambican tantalum, which sum up in 2014 to nearly 40 tons, to be compared to the 1200 tons globally produced (Bleiwas, Papp, and Yager 2015).

Several others exploitation concessions have been granted in the same zone, but they have never been exploited so far. Others concessions might be granted if new deposits are discovered – almost the entire surface between the N1 and the GNR is under prospection licenses (see Figure 58).

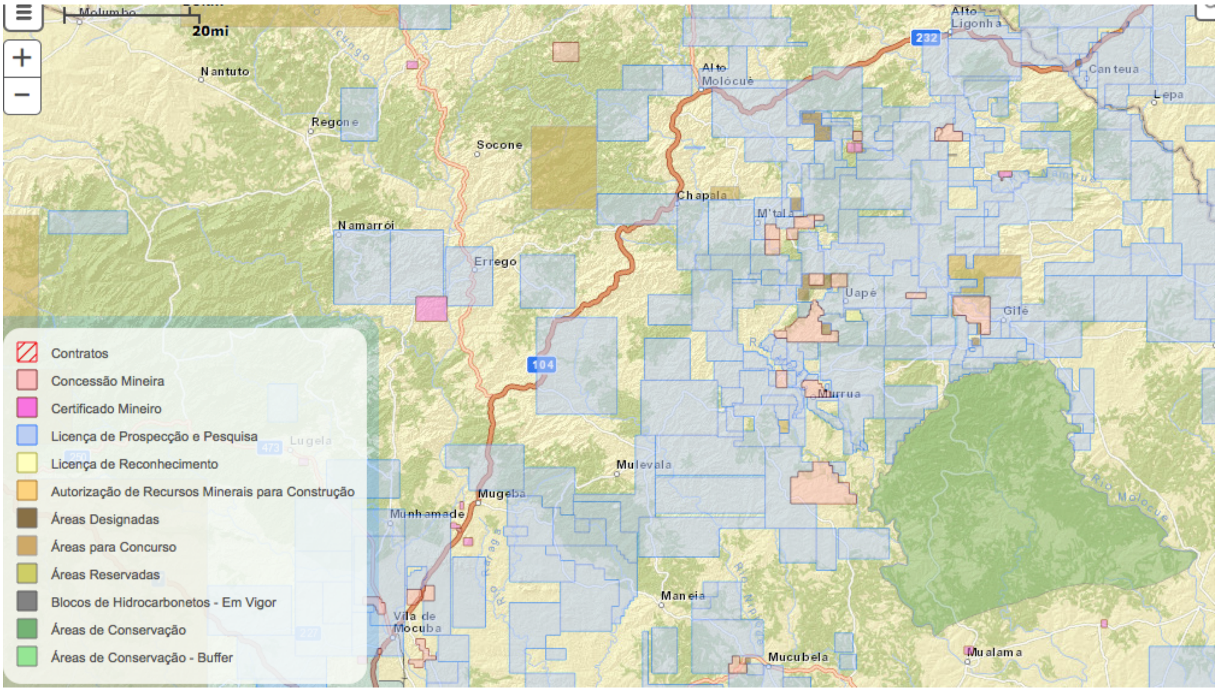


Figure 58: Tantalum mining concessions (in red) and prospection licenses (in blue) in the ZILMP area. Source: Cadastro mineiro de Moçambique

Two heavy sand prospection licenses were successful in the ZILMP area and were recently granted a concession: one in the littoral west of Pebane and the other on the coast in the Moebase area. Today, none of them are under exploitation and, as far as we know, there is no plan for a quick start of exploitation.

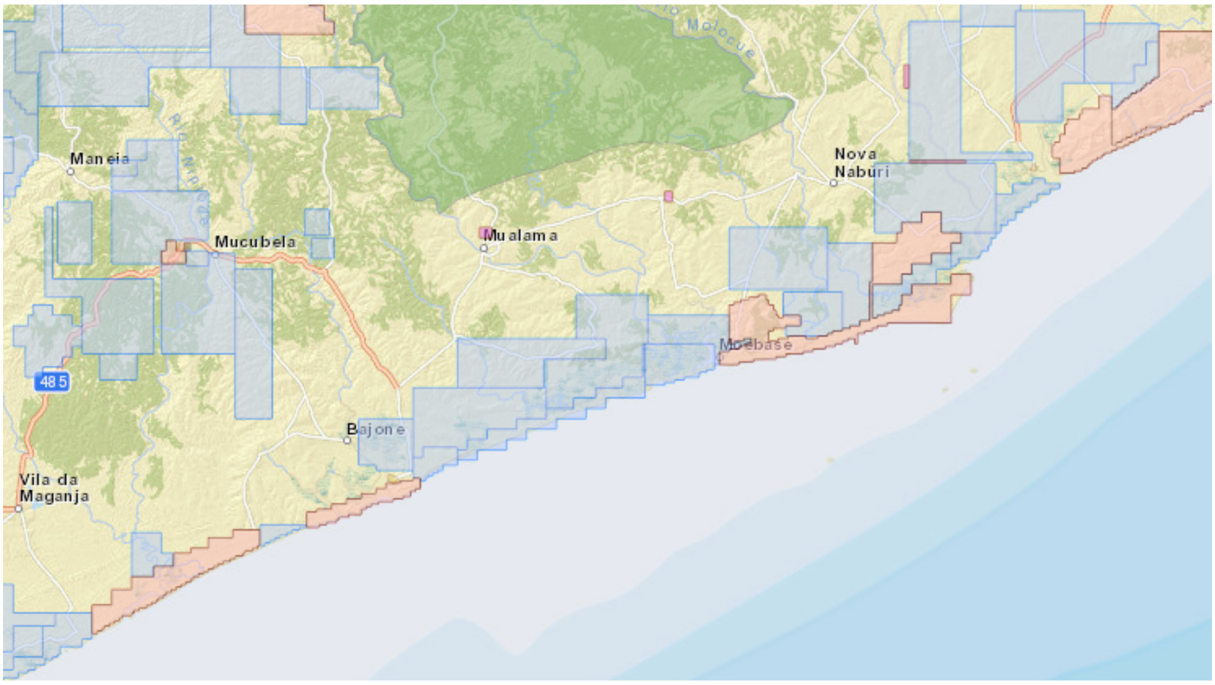


Figure 59: Heavy sand mining concession in red. Source: Cadastro mineiro de Moçambique

Legal mining prospection itself could lead to forest degradation, but the regeneration dynamics of Miombo and Mangroves should offset this degradation if the exploration is unsuccessful and not followed by human settlement.

Today, the deforestation impact of tantalum mining concessions is low, as the exploitation pit were opened a long time ago. If new tantalum site open, it could lead to enhanced Miombo deforestation. Likewise, exploitation of heavy sand could foster Mangroves deforestation.

Mining is also an indirect driver of deforestation as it provides for jobs and implies immigration, as it is observed near Murrua.

Illegal mining in the area is still residual.

4.2. Urban sprawling and Infrastructures

Today, there is no plan at provincial level for new transport infrastructure in the ZILMP area, the focus being on the improvement of current infrastructure, especially on bridges. Therefore, the direct impact on deforestation should be low in the coming years.

Nevertheless, **unexpected indirect impacts on forest, linked to infrastructure, could be observed.** During the January 2015 floods, the bridge on the Licungo River, on the road connecting Maganja da Costa to the N1 road leading to Quelimane, collapsed. Consequently, charcoal producers in the area lost their access to Quelimane market and stopped production. A few of them moved to the road connecting Maganja da Costa to Mocuba, where we observed an increase of forest degradation; the others stopped their charcoal activity.

In our opinion, urban sprawling is not a direct driver of deforestation as new houses are usually implanted on fields that already are opened for agriculture. Nevertheless, urban extension reveals a growing demography that has to be sustained by additional agriculture production.

5. Demography and population displacement

Smallholders are the main agents of deforestation and forest degradation. Demography is therefore the major underlying driver of deforestation.

We can observe four major demographic forces in the ZILMP area:

- **Natural demography, especially from the historical Molocué settlement.** Cultural and social organization, based on low centralization and little accumulation strategies (whether in the form of 'plantation' or 'cattle'), favors a diffuse population and extensive land use.
- **Resettlement of people displaced by the war.** In some scarcely populated areas and still highly forested, we can observe households re-opening plots that had been occupied a few decades ago, as attested by the presence of mango and cashew trees within the forest (see photo below).
- **Extension of coastal populations:** coastal settlements - which are denser and have received influx of people during the war - supplied by international aid, are redeploying towards forest areas. This is especially true for southern area of the GNR.
- **People who settle for mining** and gather the typical characteristics of colonization as 'veins' farms. They are especially present in the area northeast of Gilé.

Figure 60: Area of resettlement 'the presence of old mango and cashew trees in the forest area attests the former presence of farmers

It is clear that agricultural practices and deforestation dynamics vary with population density (Figure 61). Extension of small-scale agriculture through the opening of new “slash and burn” field decreases when demography pressure increases and competition for land use starts to appear. New rules on land tenure are also introduced. This is the case for example in the districts of Ilé, Alto Molocué and Maganja da Costa (Table 40) where the forest cover was largely reduced during the 90s. This is also true, to a lesser extent, in Pebane district, around the city (*Pebane Sede*), because of the small Miombo forest cover. Hence, with increasing demography of the ZILMP area, pressure on forest – and so, total deforestation - will raise while the available land for each farmer will grow rare in some districts, exacerbating the vulnerability of this population who would start to migrate towards urban centers – increasing demand for charcoal and food products from other areas - or other districts.

According to *Agrisud International* and *Etc Terra* surveys around the GNR, farmers use 1 to 2 ha each year and they can realize 2 cultivation cycles of 3.5 years long on a field interrupted by 4 years fallows. They would then abandon a field (after 11 years) and need to open a new one by slashing trees. This cycle is can apply to several fields entering in a rotation system. Of course, data on those practices are highly variable depending on geophysics conditions and on farmer ages and strategies. However, based on those hypotheses (with 1ha/yr of cultivation to be conservative) and population data (considering a farmers proportion of 80%), we calculated an annual cultivation area of 514,000 ha (confirming the result obtained in Table 27) with an annual need for deforestation of

13,400 ha for the whole district area - which is similar to the annual rate of deforestation. This calculation emphasizes that small-scale agriculture is by far the main deforestation factor. For indication, projecting this in the future with a population growth of 3%/yr lead to an increase of the annual need of new agricultural land – and so, deforestation – of 4,600 ha/yr by 2025.

Table 40: Data on population density and deforestation for each administrative post of the ZILMP area

Districts	Administrative post	Population in 2007	Area of administrative entity in ha	Population density in 2007 - in hab/km²	Deforestation 2005-2013 in ha	Areas of deforestation per inhabitant - in ha/hab	Annual deforestation 2005-2013 in ha/yr
Alto-Molocué	Alto-Molocué Sede	183,300	252,047	73	378,765	2	47,346
	Nauela	88,350	378,765	23	252,040	3	31,505
Subtotal		271,650	630,812	43	630,805	2	
Gilé	Alto-Ligonha	53,981	394,780	14	394,779	7	49,347
	Gilé-Sede	71,033	501,736	14	501,739	7	62,717
Subtotal		125,014	896,516	14	896,518	7	
Ilé	Ile-Sede	163,676	215,493	76	215,495	1	26,937
	Socone	51,550	261,685	20	87,919	2	10,990
Subtotal		215,226	477,178	45	303,415	1	
Maganja da Costa	Baixo Licungo - Nante	64,008	8, 918	73	109,607	2	13,701
	Maganja da Costa Sede	107,607	146,126	74	158,320	1	19,790
Subtotal		171,615	234,045	73	267,926	2	
Mocubela	Bajone	70,302	158,319	44	146,125	2	18,266
	Mocubela	34,964	353,108	10	353,108	10	44,139
Subtotal		105,266	511,427	21	499,233	5	
Mulevala	Mulevala - Sede	74,665	109,606	68	261,685	4	32,711
Subtotal		74,665	109,606	68	261,685	4	
Pebane	Mulela	65,041	513,379	13	513,386	8	64,173
	Naburi	59,581	345,307	17	345,322	6	43,165
	Pebane - Sede	60,711	146,793	41	146,787	2	18,348
Subtotal		185,333	1,005,479	18	1,005,495	5	
Total		**1,148,769**	**3,865,062**		**3,865,078**		**483,135**

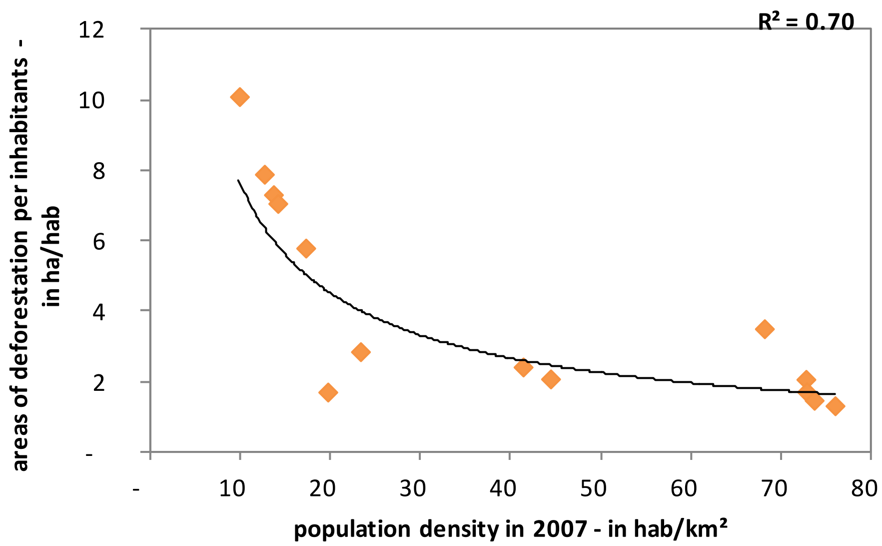


Figure 61: correlation between population density and area deforested per inhabitant

6. Summary on the contribution of the different drivers to deforestation and forest degradation

Emissions in relation to different activities were calculated in the present study as followed:

- **Emissions due to deforestation** were estimated with historical deforestation areas and an emission factor combining carbon stocks in above and belowground biomass of the Miombo forest and carbon stocks of post-deforestation land uses from bibliography (see Reference emission level and baseline for the Miombo forest section). The average emissions calculated on a 10 years reference period (2005-2010-2013) were projected on the future according to the FCPF MF.
    - The analysis of emissions due to deforestation was refined to account for emissions **relative to agriculture alone in rural areas and to those relative to agriculture and charcoal production around urban centers** of the program area. This last category was deducted from total emissions due to deforestation by estimating the areas impacted by both agriculture and charcoal production, knowing that about 10,000 ha are impacted by charcoal production alone and that an additional 10% of charcoal production is realized in fields (see Estimation of charcoal production location, intensity and impact on forest section), therefore in association with agriculture. Hence, this enables avoiding double counting for deforestation.
- **Emissions due to degradation** were estimated for charcoal production and legal and illegal logging in the corresponding sections:
    - **Emissions due to charcoal production** were calculated thanks to assessment of annual consumption in each urban center and the corresponding areas impacted, knowing the average practices of producers. According to the default factors selected to produce emission factors, estimations vary and will have to be refined if emissions from degradation are into account in the program baseline (Figure 62). Moreover, carbon stocks of post-deforestation land uses would have to be included in the analysis. Yet, it is likely that emissions from charcoal production are in between those 2 estimations.
    - **Emissions due to forest exploitation** were estimated with data on total volume officially exploited in the program area and the approximate part of illegal logging. However, a field survey would be necessary to improve the analysis if degradation is taken into account in the program baseline.

Results are summarized in Table 41.

As expected, deforestation due to agriculture alone accounts for the main part of the emissions of the program. Charcoal production impacts an area that is similar to the one impacted by agriculture but, because producers select the tree used instead of clear-cutting, this degradation entails lower emissions. However, depending on the factors used for calculation of emissions due to charcoal production, its share in the overall balance can be significant (Figure 62). Still, given the impact of charcoal production on the field, conservative hypothesis seems unlikely. According to the FCPF MF (criterion 3.3), if degradation accounts for more that 10% of global emissions, it has to be included in the program baseline. **It is therefore recommended to account for this activity in the program baseline and to perform specific study aiming at refining the factors used to assess the carbon stocks in biomass that is used for charcoal production and in the regeneration following this activity.**

As for forest exploitation, it seems to account for a low part in the global emissions of the program, as it was expected. Yet, it probably has a significant impact on floristic biodiversity and should be addressed for program co-benefits.

Table 41: Results on emissions due to different drivers for the ER program baseline

Activities included in the baseline	Causes	Estimation of mean annual areas impacted - in ha	Estimation of mean emissions - in tCO_2eq/yr	Contributions of causes to total emissions	Contributions of activity to total emissions
Deforestation	Agriculture: mainly small scale	13,721	3,064,501	83.7%	91.1%
	Agriculture: small scale + charcoal production	1,077	270,154	7.4%	
Degradation	Charcoal production (conservative hypothesis)	10,770	288,537	8.4%	9.5%
	Legal and illegal logging		37,945	1.1%	

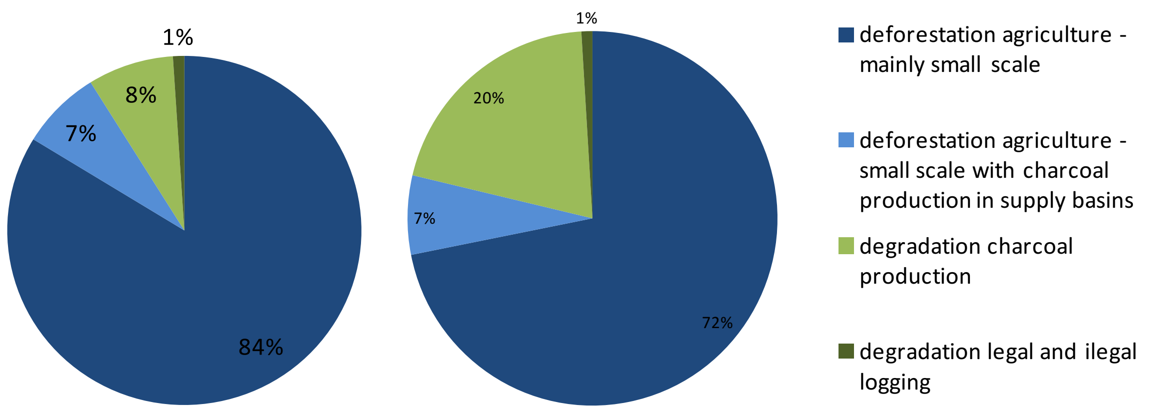


Figure 62: Part of emissions (in tCO_2eq) for different causes with the conservative hypothesis (on the left) or not (on the right) for charcoal production

7. Conclusion

Cash crops hardly have any influence on deforestation in the ZILMP area; **deforestation is nearly exclusively driven by smallholders' agriculture for maize and cassava**. Clearing new fields is a key element of smallholders' strategy to overcome fertility problems and labor constraints due to weeding.

Land-intensification would require non-volatile and increased income for investment in inputs. In the ZILMP context, it seems difficult to increase income from food crops. **On the contrary, some cash crops (sesame and cashew) present good opportunities to increase income and do not participate to deforestation. Therefore, a package that supports intensification on maize and cassava while improving sesame and cashew could be an option to reduce deforestation.**

In rural areas, only fuelwood is used as a source of energy, charcoal is produced in specific supply basin around the city of the ZILMP area. Charcoal is a complementary activity for smallholders in those basins, only 17% of charcoal production in the ZILMP is made by people for whom it is their sole activity. D**egradation due to charcoal production will have to be accounted for**, as they exceed 10% of deforestation emissions.

Forestry is a, somehow, a distinct degradation driver as it is not driven by smallholders livelihood but mainly due to international demand. Very weak law enforcement accounts for this degradation. **Degradation due to forestry could be neglected**, as related emissions are far less than 10% of deforestation emissions.

Other drivers are not significant in the ZILMP area.

Those direct drivers make smallholders be the nearly unique agents of deforestation within the program area; therefore **demography is a very important underlying driver of deforestation in the ZILMP area**.

Analysis of risk of future deforestation

In this section, we address the question of the location of future deforestation, starting from the basic assumption that deforestation is not a random phenomenon but occurs in locations that combine advantageous bio-geophysical and socio-economic attributes for deforestation agents. For instance, soil fertility and distance from forested areas, transportations or markets are likely to influence the choice of human settlement and agricultural practices, putting natural forest location at various levels of risk.

Using a Geographical Information System (GIS) and available datasets, the potential spatial deforestation factors can be estimated in any location over the ZILMP area. Their relative importance can then be tested by the empirical analysis of the correlation between (i) observed deforestation derived from the historical deforestation analysis (see *Analysis of historical deforestation* section) and (ii) datasets of geo-referenced deforestation factors. Eventually, this statistical analysis, or modeling, defines the level of deforestation risk for each spatial location ("pixel") that can be displayed in a map of risk of deforestation (or probability of deforestation). Highest probabilities are then assessed together with estimates on future deforestation areas described in the baseline in order to provide for year-by-year deforestation extent.

It should be noted that the FCPF Methodological Framework (FCPF 2013) does not entail any requirements regarding the projection of future deforestation.

Our aim is to provide a map of deforestation for the next ten years (2014-2024), based on the historical average scenario. We believed that spatially explicit information on future deforestation is very important to design the strategy of the ZILMP.

We developed a GIS and modeling approach that can be summarized by the following tasks:

- Preparation of deforestation factors maps.
- Preparation of deforestation risk maps.
- Selection of the most accurate deforestation risk map.
- Mapping of the location of future deforestation.

1. Methodology

1.1. Preparation of the deforestation factors maps

The previous section studied the direct and indirect drivers of deforestation in the ZILMP area. There are very few geo-referenced data on the drivers themselves. This is the reason why we use proxy to model those drivers. For instance, as mentioned in the *drivers of deforestation* section, charcoal activities are related, to some extent, with the distance from markets or big towns.

First, we compiled a spatial database of landscape (e.g. Digital Elevation Model) and socio-economical features (e.g. roads, town, rivers). Second, those datasets were computed to infer significant spatial deforestation factors - as describe in Table 42. The factors we used are commonly used in others similar studies (Green et al. 2013; Gorenflo et al. 2011; Vieilledent, Grinand, and Vaudry 2013) and where tested in the ZILMP context. They can be divided into three groups of factors:

- **"Landscape"**: factors that are related to bio-geophysical conditions, such as elevation or forest fragmentation.
- **"Transportation"**: factors that involve geographical distance between one particular location and another.
- **"Land tenure"**: factors that represent specific regulation rules, which can affect the rights or mobility of deforestation actors.

Furthermore, factors were differentiated according to their degree of possible alteration in the future - that is, a change due to either deforestation (e.g. distance to forest edge) or planned infrastructures (e.g. roads, settlements). This requires the development of a dynamic spatial model. We referred the factors as either "stable" or "dynamic" factors. In this study, we only considered three dynamic deforestation factors that are: (i) distance to forest edge, (ii) forest fragmentation index and (iii) distance from previously deforested land. For each modeled time step, those factors have to be recalculated.

So far, we have not investigated the land tenure factors: they will be analyzed later on.

Those tasks were performed in a GIS (*QGis*) using specific algorithms or equations - as mentioned in Table 43.

Table 42: Spatial Deforestation factors list (1/2)

ID	Name	Deforestation factor represented		
		Category	Type	Description
1	Altitude	**Landscape**	Stable	This proxy is related to various other indicators such as the distance from the sea
2	Slope		Stable	Slope intensity may be a constraint for cultivation and selected logging.
3	Forest Fragmentation		Dynamic	Forest fragmentation relates to subtle human activities such as illegal selected logging, clearing and mining.
4	Distance to the closest town	**Transportation**	Stable	This indicator relates to the access of outlets for crop production (market).
5	Distance to the closest road		Stable	This indicator relates to people access to commodities (food and material).
6	Distance to the closest river		Stable	This indicator relates to water availability for crop production.
7	Distance to previously deforested land		Dynamic	The probability of deforestation may be higher in areas that are close to recent shifting cultivation plot.
8	Distance to the closest forest edge		Dynamic	This indicator describes the availability of forest resource
9	Forest concession	**Land tenure**	Stable	It relates to regulation on timber harvest
10	Mining concession		Stable	Describe the legal mining areas
11	Protected areas		Stable	It relates to activity regulation defined within the protected areas

Table 43: Spatial Deforestation factor list (2/2)

ID	Name	Source	Meaning of the pixel value			Algorithm or equation used	Comments
			Range	Unit	Meaning		
1	Altitude	DEM, SRTM, v4	0-1552	m	Elevation above sea level	Raw data	
2	Slope	DEM, SRTM, v4	0-77	Degree	Slope intensity	Floating window	
3	Forest Fragmentation	Etc Terra, 2016	1-5	Category		(Riitters et al. 2000)	
4	Distance to the closest town	XXX	0 - 48	km	Distance at crow flies	Euclidian distance calculation	
5	Distance to the closest road	XXX	0 - 65	km			
6	Distance to the closest river	XXX	0 - 29	km			
7	Distance to previously deforested land	Etc Terra, 2016	0 - 15	km			
8	Distance to the closest forest edge	Etc Terra, 2016	0 - 4	km			
9	Forest concession	XXX	0 - 1	Category	Absence or presence	Conversion to raster	Not tested yet
10	Mining concession	XXX		Category			Not tested yet
11	Protected areas	IGF, 2015		Category			Not tested yet

1.2. Preparation of deforestation risk maps

Basically, producing a risk map implies defining correlations between observed deforestation and spatial deforestation factors. There are different ways of analyzing those potential correlations, ranging from simple statistical analysis to more complex modeling approaches. For this study, we investigated both: first, we compared pairwise influence of calculated deforestation factors on deforestation, in order to assess both the significance and relevance of such correlations; then, all these datasets were compiled into one unique stack of layers.

Modeling a risk map also requires performing a logistic regression of deforestation value, by assigning a value of "1" to the observed deforestation and a value of "0" to "no change" pixels. First, a random sample of deforested points and of "no change" points has to be created. In order to do so, we used 20,000 points of change and 20,000 points of "no change" observations on the calibration period (2005-2010). Then, an extraction of the deforestation values has to be performed on these points to build up a matrix ready for calibration. At this stage, a series of calibration tests are undertaken: they imply changing the combination of factors, or model parameters. Once validated, the model is finally applied onto the stack of deforestation factors maps, with the aim of predicting the risk of deforestation or probability of deforestation.

Those tasks were performed using the *R-stat* software, a dedicated package for manipulating raster dataset (package *raster*) and modeling deforestation (package *RandomForest*).

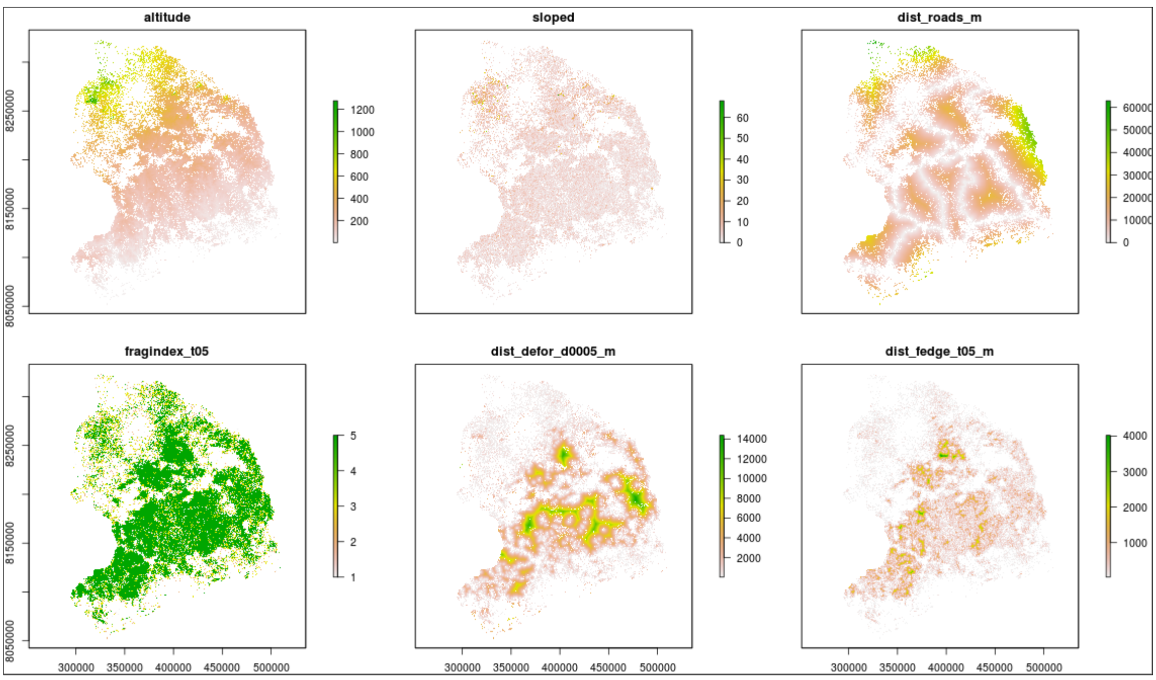


Figure 63: Illustration of spatial deforestation factors

1.3. Selection of the most accurate risk map

We used one of the assessment techniques called “Figure of Merit” (FOM) - which confirms the model’s prediction in statistical manner ((Pontius Jr et al. 2007; Pontius Jr et al. 2008)) - supplemented by traditional accuracy indicators - “Overall Accuracy” (OA) and the Kappa index (K). The formulas we used are presented below.

Table 44: Calculation of “Figure of Merit” index. Value of 0 = no deforestation and value of 1 = deforestation

		Observed deforestation	
		0	1
Predicted deforestation	0	A	B
	1	C	D

A = Correct area observed and predicted as “no change”.
B= Area of error due to observed change, while predicted as persistent.
C= Area of error due to observed persistence, while predicted as subject to change.
D= Correct area observed and predicted as subject to change.

FOM is calculated according to this equation: **FOM = D / (C+B+D)**

The value of FOM shall be compared with the total areas of observed change within the study, during the studied period. VCS VM0015 defines the guiding rule to assess the map accuracy as follow: “The FOM value shall be **at least equivalent** to the total area of change being modeled in reference region during the calibration period as percentage of the total area of the reference region”.

In this study, we calibrated the model on the 2005 - 2010 period and validated the accuracy of the model by predicting the deforestation during the 2010 – 2013 period, the overall 2005 - 2013 period being referred as the “calibration period”. The acceptable **FOM threshold limit is therefore 3,4%** (14,797 ha/y * 9y / 3,865,000 ha).

The successive tests of risk maps are then compared regarding those performance indexes.

1.4. Mapping future location of deforestation

Once calibrated, the map of risk of deforestation is converted into a map of location of future deforestation, using the quantity of annual deforestation that was previously defined or discussed. In a first attempt to define the location of future deforestation, we used the baseline scenario (see *Analysis of historical deforestation* section), that is: **14,797 ha of deforestation by year over the ZILMP area.**

This value helps identifying the location of future deforestation, by ranking the probability of deforestation value. A value of deforestation is assigned to the highest probability pixels, remaining pixels being considered as “no change” within the projected period.

2. Results

2.1. Spatial deforestation factors relative importance

We analyzed the relative importance of spatial deforestation factors for various perimeters - districts and overall ZILMP area - and using the *randomForest* algorithm. This algorithm allows calibrating a multivariate regression while estimating the contribution with unbiased estimates (Breiman 2002). Results show the high importance of the location of previously deforested plots, which is easily explained by farmers’ strategy based on the exploitation of new cropping areas next to the previous ones, for many reasons – including the existence of tracks, proximity to the house, knowledge of soil quality. Furthermore, transportation factors all contribute to a different extent to the probability of deforestation, with the same pattern being observed in each district. It is worth noting that the model performance is worse in the district of Ilé, Mulevala and Maganja da Costa.

Table 45: Relative importance of spatial deforestation factor for the 7 districts of the ZILMP and for the entire area. +++ = very important, ++ = important, + = less important. The bold character indicates a very strong importance in explaining deforestation location.

Factors		Relative importance of spatial deforestation factors							
Id	Name	Alto Molocué	Gilé	Ilé	Mulevala	Maganja	Mocubela	Pebane	ZILMP
1	Altitude	++	++	+	+	+	++	++	++
2	Slope	+	+	+	+	+	+	+	+
3	Forest fragmentation	+	+	+	+	+	+	+	+
4	Distance to towns	++	++	+	++	+	++	++	++
5	Distance to roads	++	++	+	+	+	++	++	++
6	Distance to river	++	++	+	+	+	++	++	++
7	Distance to deforestation	**+++**	**+++**	++	++	++	**+++**	**+++**	**+++**
8	Distance to forest edge	++	++	+	+	+	++	++	++

Additionally, we performed a logistical regression analysis to measure the significance of the different spatial deforestation factors (p value). The results are presented in the table X below. We observed similar general pattern, every factors contributing significantly to explain deforestation (p value < 0,001), with an exception of the “distance to the river” which seems less important (p value of 0,17). The slight difference of both metrics of importance of variable lies in the assumptions in the algorithm (e.g. independence of variable, linearity).

Table 42: Relative importance of spatial deforestation factors obtained from logistical regression

Variable	Estimate	Std.	Error	p-value	Signif.
Intercept	2.481e+00	8.517e-02	29.133	<2,00E-16	***
Altitude	6.146e-04	7.158e-05	8.586	<2,00E-16	***
Slope	-3.984e-02	4.077e-03	-9.771	<2,00E-16	***
Distance to roads	-3.148e-06	1.635e-06	-1.925	0.05427	**
Distance to river	3.508e-06	2.557e-06	1.372	0.17004	.
Distance to roads	-2.554e-05	1.706e-06	-14.966	<2,00E-16	***
Fragmentation value 2	-4.317e-01	8.673e-02	-4.978	6.44e-07	***
Fragmentation value 3	-5.235e-01	7.982e-02	-6.558	5.44e-11	***
Fragmentation value 4	-3.609e-01	9.797e-02	-3.684	0.00023	***
Fragmentation value 5	-9.531e-01	8.169e-02	-11.666	<2,00E-16	***
Distance to past deforestation	-1.516e-03	2.585e-05	-58.662	<2,00E-16	***
Distance to forest edge	-1.014e-03	1.031e-04	-9.835	<2,00E-16	***

Significance codes: *** > 99%, **, >95%, * > 90%, . >80%

2.2. Preparation of risk maps for deforestation

The model of risk for the entire area was finally used to predict the probability of deforestation at every pixel location using the *randomForest* algorithm. This algorithm was preferred mainly for its ability to handle correlated variables and complex (non-linear) relationship between factors. It was performed using the calibration datasets representing the deforestation process between 2005 and 2010. We based the prediction on the 2010 forest state. The final output is a map of probability of deforestation at 30-meter pixel scale, displaying values ranging from 0 (very low probability of deforestation) to 1 (very high probability of deforestation).

2.3. Quality assessment of the map risk

We analyzed the map of risk by predicting the location of deforestation for the 2010 -2013 period and by applying the observed area of change (66,776 ha). Then, we applied a random sample of 20,000 points on the forest cover in 2010 and generate the confusion matrix presented below.

Table 46: Confusion matrix and quality assessment indexes for the calibrated model

		Observed deforestation	
		0	1
Predicted deforestation	0	14,441	482
	1	406	81

OA	94.2
FOM	8.6
Kappa	12.4

The measured FOM is low but above the standard requirements of 3.4%, as described above.

Moreover, we visually inspected the output to explore the predicted deforestation pattern and compared it with the observed deforestation (Figure 64). It appears that the map correctly matches the observed deforestation patterns when it occurs on the edge of the forest edge and close to towns. This “frontier deforestation” is linked to village expansion and new human settlements associated with the opening of new fields after soil fertility depletion of the ancient ones or for new households. However, we found significant omissions in areas where deforestation occurs within a forest massif. These deforestation patterns are related to different activities that may be mining settlements or wild fires, which may lead to land clearing. Although those so-called “mosaic deforestation” are common in the ZILMP area, the projection process cannot predict them – a failure that contributes to the overestimation of frontier deforestation (Figure 64).

The solution to “capture” land clearings within forest massif is not obvious as we lack a clear spatial deforestation factor to represent this phenomenon. In spite of appearances, those land clearings are not random within the forest massif: further research is required to better identify the activities, drivers and agents of this deforestation.

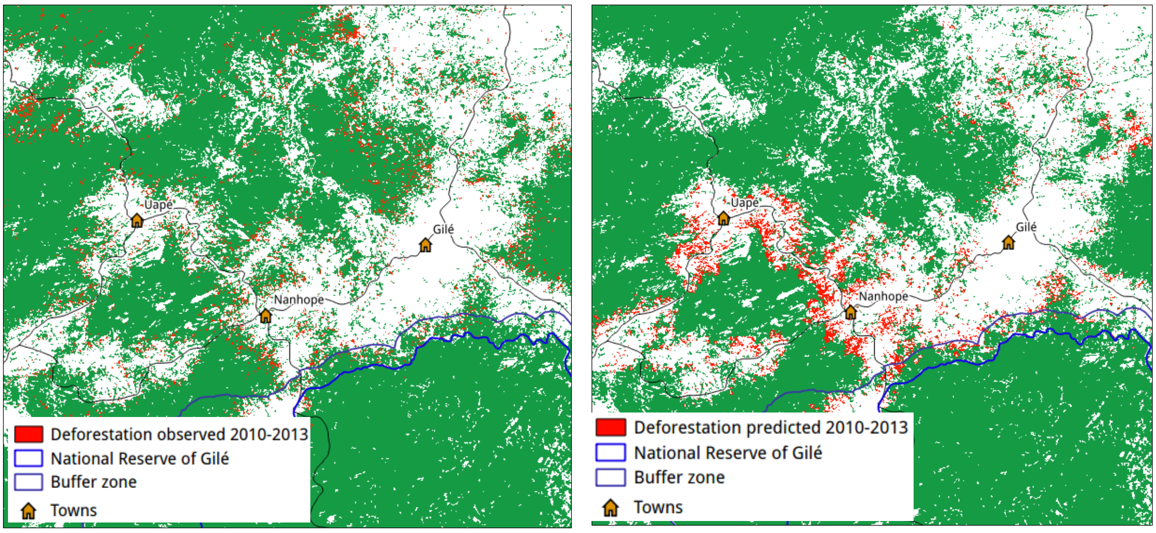


Figure 64: Visual comparison of observed and predicted change for the 2010-2013 period

2.4. Future deforestation location

Future deforestation location was determined for the 2014 - 2024 period using the historical average scenario for deforestation area. The deforestation for this period reaches 14,797 ha.

This surface was applied to the risk map by thresholding the highest probability value. The result is presented in Figure 65.

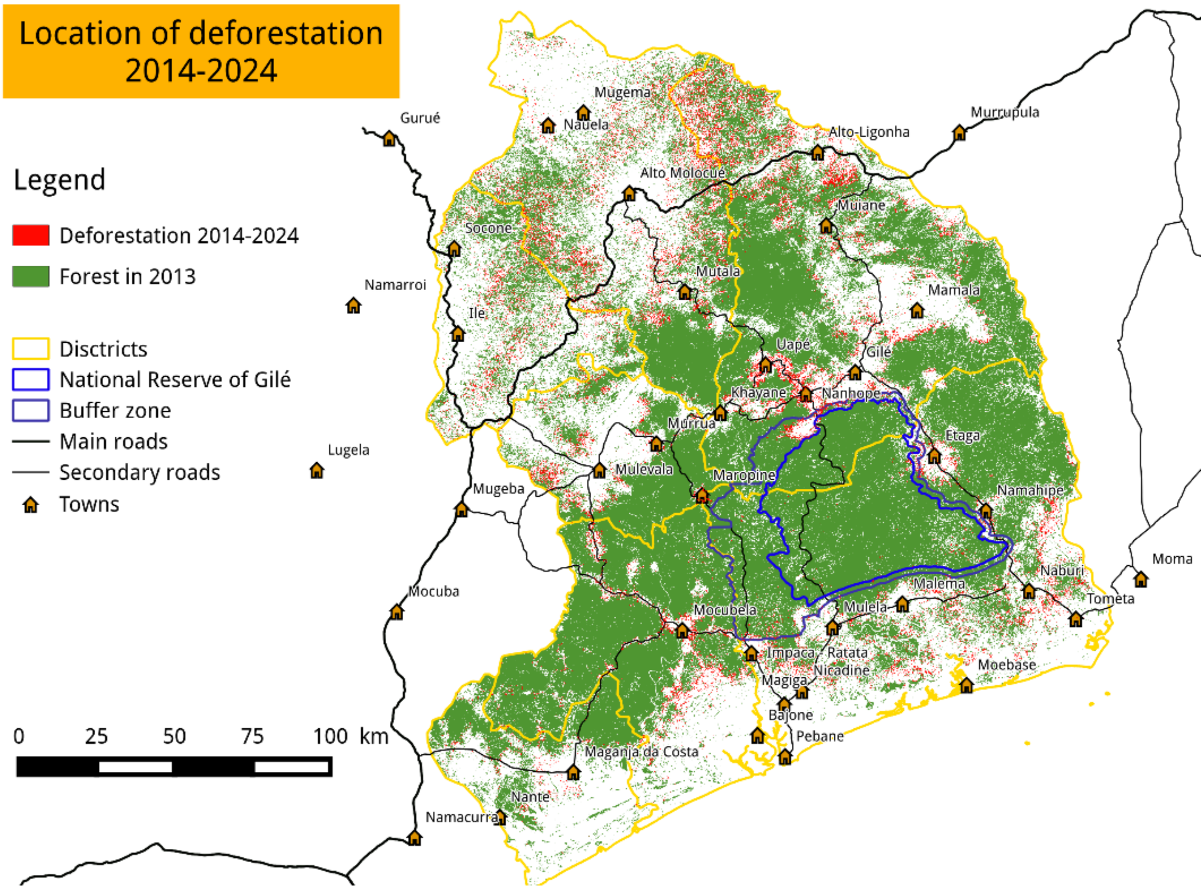


Figure 65: Location of future deforestation for 2014-2024 (historical average scenario)

2.5. Risk analysis and REDD+ program management

From the ZILMP map risk, seven maps for each district were prepared and are available in Annex 6. While those maps describe very fine information at pixel level (30 m), this information should be aggregated at a scale that enables to make useful recommendations for policy decisions.

Hence, we conducted a detailed analysis based on those maps and local knowledge to delineate three level of risk and made further recommendation of actions for each category. This information is presented in the table below. At the end we aggregated the probability value by summing them on a 2 kilometers grid.

Table 47: Risk categories for risk mapping

Id	Name	Description
1	Very high risk	Those area are of major threat and should be considered in priority for actions
2	High risk	Those area are under threat in near term and should be planned
3	Low or no risk	Those area may be threaten in the long term

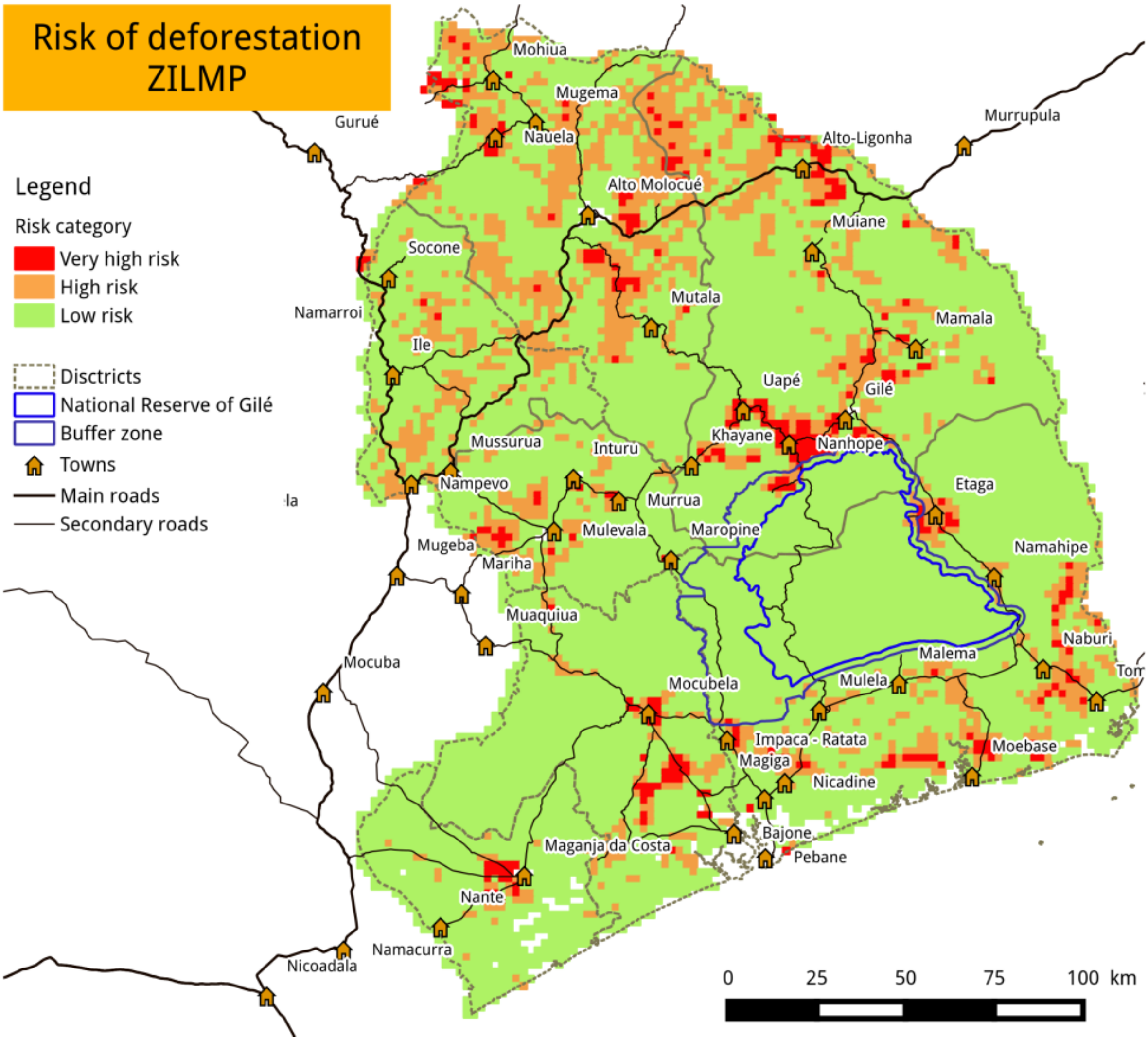


Figure 66: Risk map by category of risk

3. Conclusion

The present section sets a transparent methodology to map the risk of deforestation and produce a map of future deforestation.

Spatial analysis of the location of deforestation and of spatial deforestation factors resulted in the assessment of the relative significance of spatial deforestation factors. **It appears clearly that the areas close to already deforested plots are more likely to be deforested in the future**. The transportation factors (distance from roads, towns or rivers) also plays an important role, but to a lesser extent. The same patterns were observed for the 7 districts.

While it is still being improved, the model that was used to predict the risk of deforestation shows an acceptable level of agreement. Indeed, the commonly used risk map quality indicator, FOM ("figure of merit"), is above the required standard. Visual inspection of the probability of deforestation also shows a good agreement with expert knowledge, although it fails to capture small clearings within forestlands.

By projecting baseline scenario over the next decade, we were able to produce future deforestation maps. Those maps underline the high risk of deforestation in the northern districts.

Providing such geo-referenced information will contribute to improve the emission baseline estimation, by combining those maps with the biomass stock map. Furthermore, it helps decisions makers focusing on remaining forested areas that are at high risks due to a combination of significant factors for deforestation agents. For instance, lands that underwent important past deforestation, close to towns and with high density of roads should be considered as a matter of priority.

Options to reduce deforestation and forest degradation

The options that we are suggesting are based on the analysis of the drivers presented in the previous section and build on the options proposed in the ER-PIN in order to precise them and their implementation methodology, or to dismiss some of them.

1. Agriculture

As stated in the *Analysis of the drivers of deforestation* section, small-scale agriculture is by far the main reason of deforestation. Smallholders deforest to produce maize and cassava and new plots reduce labor constraint related to management of soil fertility and weeding during the peak season. Deforestation mitigation actions will have to incorporate those constraints by acting on two levers:

- With no access to external inputs, **agro-ecology intensification is the only response to fertility needs and weeding problems**.
- In order to ease risk taking, innovation adoption and investment in intensification, **the program should help secure producers' income** with a value chain and a risk management approach that overcome labor productivity issues.

Table 48: Main characteristics of the proposed options

Types of Activity	Method of implementation	Means of implementation	Type of research-action needed	Potential partnership
Agro-ecology Intensification for subsistence crops	Double differentiation according to: • Agro-ecological context • Individual households' strategies	- Strong & regular field presence - Differentiated protocols implemented by committed & highly qualified extension agents	- Experimentation in smallholders' environment - Understanding of smallholders' expertise	- Structures that are already working in the area with rural households (public, NGO or private) with result-based payments and acceptation of the implementation method
Increasing smallholders' revenues, including through no-deforestation value chains, especially cashew and sesame	Large scale extension with a common package	- Initial training (2 or 3 modules) and support during the commercialization period - Possible use of ICT -Need for market analysts	- Local and international demand integration - Market analysis	- Up & downstream private sector: • Upstream: input supply for increased productivity • Downstream: commitment from local and international buyers for sustainable and fair commodities

1.1. Agro-ecological intensification of subsistence crops, especially of maize and cassava

Classic options to overcome fertility and weeding issues in a labor-constraint smallholding are the use of external inputs for fertility (from livestock and/or mineral fertilizers) and for weeding (chemical control or mechanic control of weeds). Let's first examine those options in the context of the ZILMP.

***Option livestock**:* Cattle cannot be introduced due to trypanosomiasis prevalence. Goats were successfully introduced in Namurrua, northeast of GNR, in the 2000s. Although smallholders were very satisfied, it was a failure in terms of deforestation: animals were left scavenging around the huts in the *champs de case* and smallholders had to open new *machambas* in the forest to offset production loss.

Introduction of small livestock should come with strong technical advises on semi-confinement techniques with the inclusion of different types of feeding (fodder hedges, fodder shrubs on fallow or unused *ruinas*) and systematic valuation of crop residues. If chosen, this option should be tested at a very small scale on the basis of a solid feasibility study. As for us, we do not recommend it, because it is too risky.

***Option Mineral Fertilizer**:* it is a classic option to offset the decline in natural fertility. However in Mozambique, fertilizers are entirely imported and very difficult to find locally. Their price on the Mozambican market is very high and smallholders cannot afford them. For example, 300 kg per ha of NPK should be applied on maize for a return ranged from 2 to 3t/ha. Observed retail prices of NPK in Mozambique are around 1 USD/kg, therefore the cost per hectare would be 300 USD for a gross profit ranging from 260 to 390 USD per hectare, depending on yield. Investment in fertilization is very risky for a smallholder. For such a REDD+ program, lowering the cost of the fertilizer nevertheless seems out of reach. **Therefore, we do not recommend the mineral fertilization option**. In addition, production of mineral fertilizers is also a source of GHG emissions.

Options related to weeding: The chemical control of weeds is facing two challenges: the high cost of chemical inputs (the value chain in Mozambique is quasi inexistent) and the environmental risk (loss of biodiversity, loss of nutrients cycles, toxicity…). The mechanic control is also not suitable in this social and economic context: farmers' equipment is very basic and mechanization will not be economically viable without access to markets.

Consequently, we believe the only option to overcome fertility and weeding issues in the ZILMP area is the **dissemination of intensive agro-ecological practices for food production** – first, in order to improve maize and cassava production.

As already seen, smallholders in the ZILMP area have a small capacity of innovation because of the rarity of external resources to test new approaches. Smallholders' strategies are constrained by labor availability objectives. **This implies that the agro-ecology practices to be promoted for intensification should seek, first, to increase labor productivity** (and not production per hectare *per se*, an objective that could require an increased workload).

Although the technical content of agro-ecological intensification supports should take into account individual households' strategies and be modulated according to agro-ecological contexts, a **'classic' agro-ecology package should apply as a common basis for the whole ZILMP**. This package is based on:

- **Improvement of crop successions and associations** (with possible introduction of new species, especially legumes).
- **Cover crops for effective weed management and better fertility** (diminution of water losses, enhancement of nutrient availability and soil biotic activity).
- Selection of useful trees to be protected when opening fields.
- Biomass enrichment in fallows.
- Conversion of *ruinas* into agroforestry plots (including economically valuable fruit trees: cashew for the international market).

It is to be noticed that, whereas association with legumes is already common in the area - it may be because of previous extension programs or as a substitution for proteins in the absence of livestock - cover crops, which are the very foundation of agro-ecology, are totally absent.

Agrisud International is currently testing different agro-ecological systems with communities around the GNR.

On that basis, and as a first approach, below are some examples of refinements that could be added in three specific demographic and agro-ecological contexts.

4. Zone 1: Deforested areas where there is very little fertile land reserves, as Ilé & some parts of Alto-Molocué district

These areas are characterized by a sharp decline in fallow time, increasing population density and difficulty to reuse abandoned lands (*ruinas*) because of weeds and very low fertility.

In addition to the classic agro-ecologic package, landscape improvement activities could help benefiting from the entire territory:

- In hilly landscapes (especially around Ilé): **crops that follow contours lines**[9] would improve water management and fertility.
- **Development of lowlands**: lowlands exploitation is limited because it requires intense labor and because few market opportunities actually exist (especially for perishable garden vegetables). However, there is a potential for development with (i) the introduction of new techniques facilitating the work (e.g. on rice cultivation: new tools suitable for soil preparation or post-harvest treatments); (ii) the introduction of new productions, especially extensive fish farming. Those introductions should be first tested at a very small scale, on a voluntary basis, bearing in mind the narrowness of local markets. A specific feasibility study would be required (technical, social and economic development of extensive fish farming in the lowlands of the area).

5. Zone 2: Fairly deforested areas with significant presence of cashew trees; e.g. Malala, Gilé District

These areas are characterized by a fairly ancient presence of agriculture, with many cashew trees constituting a 'quiet annuity', which are therefore extensively cultivated. The density of cashew 'plantations' is very low, making maintenance be difficult. Forest encroachments are still important and usually motivated by the search for better fertility to increase labor productivity. Plots are then abandoned, because they are too difficult to work on. In this area, as sesame and cashew represent more than 50% of cash income, they constitute a strong opportunity for improvements.

In addition to the classic agro-ecological package, the activities below related to the intensification of cashew trees could be promoted:

- **Maintenance & rehabilitation of cashew plots**: cleaning and pruning, preservation of natural predators - especially red ants… There are already a lot of available training materials, for instance from the *African Cashew Initiative*[10] or from *Rongead*.
- **Densification of the existing cashew plots**, from scattered trees to real plantations. There is great potential at this level, confirmed by the satellite images of the Mamala area. Systematic densification would be based on two axes: distribution (starting with INCAJU nurseries) and marketing support (see following section) to help structure the production.

[9] See for instance the agro-ecology manual by Agrisud International: http://www.agrisud.org/wpcontent/uploads/2015/11/Agrisud_eGuide2010_en/as_eguide2010bis_en.html

[10] see for instance http://www.africancashewinitiative.org/imglib/downloads/training%20material%20Portu/2011_03_03_Reabilitacao%20do%20cajual.pdf

Figure 67: Plantation that could be densified in Mamala

- **Support for the fight against mildew and powdery mildew**, which are drastically limiting production. Densification should lower the relative cost of spraying.

- **Improvement of productivity of the oldest trees, trough coppicing**. Because the loss of production is significant during 3 or 4 years, this financial loss should be balanced with intercropped productions that could be sold (sesame or peanuts, for example). With coppicing operations, we can renew old cashew trees while enjoying their well-developed root system.

Figure 68: Coppicing old cashew trees. Left: Touting. Center: Grafting. Right: Graft with fruits one year after

6. Zone 3: Deforestation fronts around the GNR

The classic agro-ecological package could be easily mixed in this zone with the promotion of cashew trees. To the contrary of zone 2, since zone 3 doesn't have a lot of cashew 'plantations' and has limited *ruinas* surfaces, **cashew trees would be promoted in agroforestry schemes: low density would be fostered with intercropped dwarf varieties, with relevant successions and associations of food crops**.

Similarly, depending on farms' location, crops that could be sold on local markets should be supported - for instance, pineapples could be planted in corridors near Gilé.

Besides the introductions of livestock, mineral fertilization and agro-ecology, other innovative and more technical solutions exist to improve fertility. For instance, natural phosphates could be mixed with crops residues and animal manure to improve the physical and chemical properties of composts (residues of crops or animal manure can be mixed with phosphate rocks). Mycorrhiza could be introduced in rice. Although those 'technological' solutions are possible, they are costly options due to the lack of providers on the Mozambican market. Nevertheless, they could be tested as pilots in some very specific locations.

1.2. Increasing smallholders' income, including through the promotion of no-deforestation value chains

Securing farmers' incomes in the ZILMP area should facilitate risk taking and the adoption of new agro-ecological practices, described above. To this end, **sesame and cashew** should be supported as a matter of priority (see the *Analysis of the drivers of deforestation section*). Others commodities such as peanuts and beans could also be targeted.

Those two crops are the main sources of households' incomes and are characterized by significant volatility. A real potential exists for improving the terms of marketing

Smallholders have to deal with local prices volatility, which depends on global market and of the local structure of the value chain - weak organization of producers, low quantities marketed, etc. Currently, producers' commercial strategies are based on minimum risk taking: they sale the majority of their products immediately after harvesting, in the numerous outlets on the roads that serve the area. This strategy is coherent with local constraints: limited market information and limited time for selling in certain parts of the ZILMP area, which can quickly be landlocked during the rainy season.

However, it is possible to act on specific levers. We observed significant selling price disparities between producers, depending on the level of organization and of proximity to collectors. Meaningful discrepancies between local farm-gate and international market prices for RCN, which cannot be explained by collection costs, were also noted.

Given this, we believe it is necessary to help producers to better market their products and to manage risks. At this level, three activities can be considered:

(a) Support the production and marketing of cashew and sesame producers, those two commodities being the most fast growing industries in the area, for which international demand is clearly identified.

(b) Promote no-deforestation value chains.
(c) Foster the creation of added value through marginal land development and development of post-harvest activities on interesting products.

1.2.1. Support the production and marketing of cashew and sesame producers

Marketing could be supported in two ways: i) with a facilitated access to information on prices and ii) with support to producers in their collective organization: sales consolidation and improved storage based on a proper market analysis.

The activities to be implemented by the program are presented below.

1. Identification of producers

A survey will be conducted at the beginning of the project to define producers' plots (practices diagnostic and parcels' conditions) and target the relevant technical support (coppicing, enrichment, pruning, phytosanitary treatments, etc.).

2. Good practices trainings

Those trainings on cash crops will complement the agro-ecology support for food crops that was explained above, and will be modulated according to agro-ecological conditions in order to avoid a prescriptive top-down.

- *Cashew Training*: Modules will be designed on the basis of existing literature (ICA-GIZ, Rongead, Agrisud) focusing on orchards creation & maintenance; harvest and post-harvest techniques.
- *Sesame Training*: A diagnosis will be made on cultural practices and species that are locally available (specifications, availability on the local market, adaptation to agro-ecological conditions). A specific group of farmers will be trained in seeds multiplication for distribution. A module on good practices for production, harvest and post-harvest will also be designed. (References exist: Rongead, GIZ).
- *Peanut Training*: in case of rising market demand, a specific module could be designed accordingly.

3. Market training

The 4 'Market training' modules will aim to enable producers to better understand market conditions in which they operate and provide them with marketing assistance tools. The four modules will address the following themes:

- Why do prices in agricultural markets change?
- What is an agricultural value chain?
- How to sell better individually?
- How to sell better through collective organization?

The modules will be provided by extension agents trained by an international expert.

4. Sales bundling and RCN quality assessment training

Quality of RCN is important for processors. Only leaders will be trained to assessment and quality improvement techniques.

5. Marketing advices during the sales campaign through SMS

Personalized marketing advices will be provided to producers on a regular basis, following a logic of business risk management.

The following steps should be respected:

- Registration of local information: quantitative and qualitative.
- Compilation and analysis by a local specialist previously formed in market analysis.
- Production of prospective notes that describe market conditions and provide advice to different types of actors: producers, traders and processors.
- Dissemination of messages: newsletters, SMS, web blog.

This activity will be undertaken in partnership with the African Cashew Alliance (ACA) and Nkalo Service, who are already providing this kind of information on African cashew and sesame markets.

The activity should be implemented through:

- The training of extension agents for collecting information.
- The creation of collection files.
- The support of a Local Training Analyst.
- The designing of a SMS broadcast / web platform.
- The registration of producers of on the platform.

This will imply (i) international technical assistance for training; (ii) technical support for the platform and (iii) partnerships creation with telecom operators.

1.2.2. Promote no-deforestation value chains

The above-mentioned activities are suggested based on the assumption that increasing smallholders' income through cash crop value chain would foster the intensification of maize and cassava culture. To go further, we are trying to link non-deforesting cash crops to deforesting food crops through the promotion of no-deforestation value chains.

As part of the 2014 New-York declaration on forests, worldwide major key players of agricultural commodities committed themselves to provide for only no-deforestation commodities. Today, many international buyers are interested in commodities coming from REDD+ jurisdictional programs. Some of them are already interested in cashew and peanuts from Zambézia.

A possibility would be make smallholders enter a contract farming scheme, in which they would receive a premium on their cash crops conditional on good practices on their maize and cassava. Smallholders' production would be certified (fair-trade and organic); deforestation would be monitored by ground survey and satellite. A national transparent and freely available forest monitoring system would facilitate such a no-deforestation certification.

This activity would focus on a priority basis on areas where forest cover is still important, in the South. Actions should be as followed:

1. **Search for market opportunities rewarding sustainable practices**

It will be necessary to identify a long-term and reliable demand to provide incentives for smallholders. The program will look for local or international partners willing to buy low deforestation certified commodities in the long term (organic and fair trade will also be considered).

2. **Launching a call for proposals on 'low deforestation commodities' to finance private sector actions that are in favor of contracting with small farmers who are engaged in sustainable production patterns.**

Eligible actions would be:

- *Support for the establishment of certification* (fair Trade, organic agriculture): creation of producer organizations, implementation of Internal Control System, management of certifications fees.
- *Support for the establisment of a traceability system*: this could be achieved via technical assistance to companies contracting with small producers: support for the designing of contract scheme; support for the identification and codification of producers; support for TIC utilisation and the use of information and communication technologies; commissioning up of the monitoring of producers and monitoring compliance of 'no deforestation ".
- *Help companies to acquire technologies that limit the use of wood* in their transformation process (biogas, gasification).

Each tender will include the terms of funding, the evaluation criteria (impacts on producers and deforestation, effective operation of the company identified market, etc.), beneficiaries' counterparties and monitoring and evaluation methods.

3. **Monitoring of no-deforestation value chains:**

Monitoring would cover producers' incomes, the impact of value chains on income, adoption of good practices and the analysis of their effects on deforestation.

1.2.3. Foster the creation of added value through marginal land development and the development of post-harvest activities on interesting products

1. Market studies for food crops improvements for local market

Identify possible demand changes linked to products quality (e.g. High Quality Cassava Floor) or new products (vegetables, fruits, NTFPs). Those activities would focus on areas where forest land reserve is limited (Ilé, Alto-Molocué).

Based on those studies, the project may direct accurate technical and financial support to the most profitable segments.

2. Call for proposals for micro production (eg. low-land developement) or processing project (eg. cassava mills).

Micro productions projects will be elaborated with the communities. Development of marginal farmland - because of low productivity or important necessary work load - will be set on a priority basis. The projects will focus on access to micro-mechanization, relevant equipment to improve tillage in lowland and equipment for contours agriculture.
Processing micro-projects will focus on products identified by the market study. They may relate to support for investment in equipment (crusher, micro-milling, pre-baking unit or dryers, Kenyan type of bee hives for projects) and in marketings tools (packaging, labels, participation in fairs). Technologies relying on renewable energy could be included (improved drying ovens, biomass utilisation).

1.3. Method and means of implementation

It is necessary to emphasize the strategic importance of method and means of implementation. In the case of agro-ecology, to date, there is no ‘one size fits all’ solution. Progressive adoption of ‘good practices' by rural households requires the operators to adopt a pragmatic approach, close to household concerns, while integrating local and international economic dimensions.

The above-proposed actions imply, to different extents, a strong local support device. Extension agents will have to integrate individual stallholders’ strategies into their work and build adapted field protocols. Being an extension agent supposes a strong agricultural background, a good ability of appreciation of farmers' strategies - including a capacity to analyze land, labor and capital use in smallholdings, as well as risk management strategies - and an ability to design *in situ* protocols, including both farmers' issues and agro-ecology requirements.

The project should therefore be based on a dense network of extension agents – whose training requires heavy investment - in line with the quantitative objectives of the program. Either public, private or civil society partners could manage the extension agents, as long as they commit to following the program guidelines:

1. Diagnostic of the agrarian system.
2. Identification of producers' typology.
3. Protocol design.
4. *In situ* support for implementation.

Regarding the agro-ecology support, we recommend a ratio of 1 extension agent for no more than 50 households. The ratio for value chain development could be 1 extension agent for 500 households - the support does not have to be so much modulated according to households; improvement of marketing will also be supported by new technologies, like SMS diffusion.

For us, the basis of agricultural extension is:

- The competence of extension agents in agronomy: conservation agriculture is based on complex technical itineraries and requires an accurate understanding of ecosystem functioning.
- Provide for practices compatible with smallholders' strategies. This requires a lot of small adaptations from one micro-region to another, from one peasant to another.
- Ensure that advise are timely and frequent. This supposes a small number of smallholder per extension agent.

If those three criteria are met, all extensions models are worthwhile: Public, private, NGO, emerging producers…

2. Options concerning bioenergy consumption and production

Whereas charcoal demand will increase with urban population growth, wood resources will continue to diminish, which may lead to charcoal producers extending their supply basins or using other species – with poorer properties. The charcoal value chain will have to adapt. Specific actions should be undertaken in order to reduce the impact of this economic activity on forests; they should entail wood resources management, carbonization techniques improvement – in order to decrease the quantity of biomass that is used – and better consumption dynamics.

2.1. Options to improve bioenergy production

In order to meet market demand and achieve the same level of production for the use of less wood, production can be improved through several techniques. **Currently, producers**

use low yields traditional kilns. The high number of small producers at the beginning of the value chain (Table 33**), makes it difficult to promote industrial techniques. However, the improvement of traditional techniques only requires low investment**:

- Training on kilns monitoring during carbonization can help producers to avoid losing too much wood during the process. However, as it is time consuming for the producers, it may be difficult to have significant results.
- Yields can be enhanced through the use of dry wood that has been set aside for a month before carbonization (Pinta et al. 2012; Schure et al. 2011).
- Other traditional techniques can be diffused to improve yields. For example, the use of casamance type kiln (Figure 69) that are characterized by the addition of a small smokestack (at low cost) can improve yields, but also decrease carbonization duration, which can participate – if less time-consuming - to improve monitoring of the carbonization step (Maurice and Le Crom 2014).

Figure 69: Pictures of a casamance type kiln[11]

In order to support charcoal producers in improving carbonization, trainings can be delivered to producers who will be previously organized into professional groups. Leaders will be identified: they will be responsible for handling the techniques and transmitting them to other producers. Trainings will focus on the improvement of traditional techniques - management of humidity rate, temperature, duration of the pyrolysis, shape of the oven (Vos and Vis 2010) - to increase average yields from 20% to 25%, without any additional investments. Demonstration kilns will be monitored to measure yields.

Within each supply basin (see Figure 50), and depending on budget allocation, we suggest targeting activities on the previously identified main production villages only (Table 33).

[11] From https://energypedia.info/wiki/La_Production_du_Charbon_de_Bois

Indeed, location of production villages depends a lot on city supply basins: production zones can either be concentrated on few villages only, representing more than half of the supply basins production (for instance in Alto-Molocué basin) or be regularly disseminated between a large number of villages (for example in Ilé basin), as shown in Figure 70.

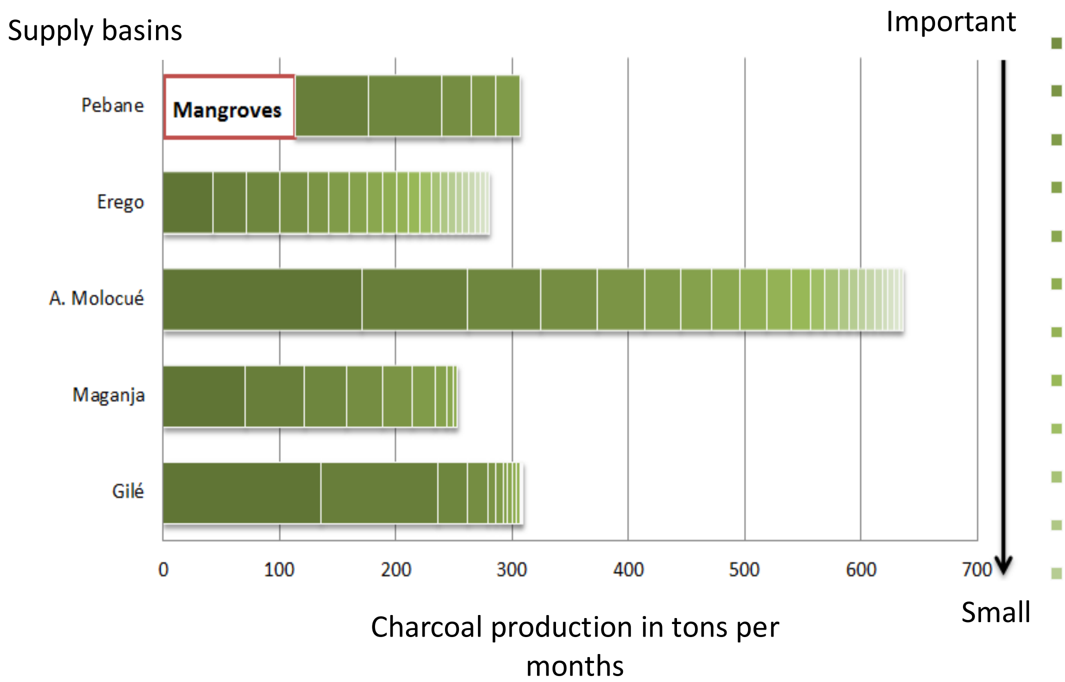


Figure 70: Distribution of charcoal production (in t/month) in each village of the supply basin of each city included in the program area

2.2. Options on bioenergy consumption

Although charcoal consumption per inhabitant and per year in the ZILMP area (0.54 m^3/in/yr) is relatively low compared to the national average (0.96 m^3/in/yr - Falcão 2008) or to national data from other countries (minimum of 0.55 m^3/in/yr for Senegal and maximum of 1.77 m^3/in/yr for Soudan – FAO stats), the proportion of urban population using charcoal is high (more than 80% for 3 out of 5 cities - Table 32) compared, for example, to Maputo (51% in 1997) or Quelimane (67% in 2015 - Julião 2015). Those differences are explained by the substitution of charcoal by other sources of energy (gas or electricity) in bigger cities of Mozambique, where there are more accessible and where population has higher level of revenues to pay more expensive energy. Populations prefer those alternative energies because it is cleaner – charcoal generating toxic smoke during its use. The promotion of this type of energy is therefore necessary but the offer for electricity is already relatively good and need to be maintained, or improved, while revenues need to increase for people to be able to afford electric stoves. Policies to favor employment will therefore contribute to lower deforestation.

At the same time, charcoal cookstoves can be improved to consume lower quantity of charcoal for cooking. Improvements can be done by hand[12] and are then adapted to local artisans. Improved cookstoves are more expensive but they allow beneficiaries to realize important and rapid savings on the energy budget. Those savings usually contribute to a rapid diffusion of the cookstoves. To initiate their diffusion, trainings to cookstoves makers in each cities and promotion of the benefits to retailers and users would be necessary. To foster interest in this technology, efficiency on the savings of wood-fuel must be demonstrated to households and mechanisms must be put in place to help them accessing the technology. For example, small loans to poor households could be proposed for them to buy their first improved cookstoves. Solar cookers can also be disseminated and locally constructed by local artisans after a relevant training[13]. However, the impossibility to use those cookers during rainy days and at night, as well as higher costs, may be an obstacle for most households. Nevertheless, if this technology is adopted, it will significantly reduce charcoal budget during sunny days. For this kind of solution, financial support from the government or NGOs is necessary. For diffusion of improved traditional charcoal cookstoves and solar cookstoves, the main consumption centers of charcoal shall be targeted: Alto-Molocué is a priority.

Figure 71: Pictures of hand made by local artisans improved charcoal cookstoves (on the left) and solar cooker (on the right)

2.3. Management of wood resources

In order to perform a sustainable management of wood resource for charcoal production, several alternatives can be considered:

- The introduction of energetic plantations with high growing rate species.

[12] See the following website for several techniques of construction of improved cookstoves: https://energypedia.info/wiki/Cooking_with_Charcoal

[13] See the relevant website for hand-made construction of solar cooker: https://energypedia.info/wiki/Cooking_with_the_Sun

- The use of bio-resources, other than wood, to produce charcoal briquettes.
- The development of natural assisted regeneration techniques on deforested or degraded areas.

2.3.1. Plantations:

For charcoal production purposes, plantations in savanna lands of fast growing species are relevant, in areas where decreasing wood resources cannot be used in a sustainable way. This is true for Alto Molocué and Ilé (Table 33). Plantations wood can replace natural forests wood, reducing pressure on this ecosystem. Fast growing species that are suitable for charcoal production - high growth rate, good calorific value and adaptation to local soil fertility and climate - usually are exotic species (*Albizia*, *Acacia* or *Eucalyptus* species). Therefore, in order to limit their impact on local biodiversity, plantations shall be located on already degraded savannahs where protected species of flora and fauna do not exist. This is usually the case of the areas surroundings cities, which have the advantage of reducing costs for charcoal transport to city centers.

If plantations are concentrated in one area, investment can be made to build semi-industrial kilns to produce charcoal (Maurice and Le Crom 2014) and to buy vehicles to transport wood and charcoal. Because the value chain does not present a high level of organization, it would not distort a well-functioning chain but will rather be a source of employment in urban centers. A local private company would ideally manage such an initiative and charcoal producers will be targeted as employees in order to provide them with an alternative low-impact activity. Management of such industrial plantations includes the supervision of nurseries, plantation, forest stands cut and replacement of dead trees, bush fires, carbonization cycles at the relevant periods and selling of charcoal.

In the meantime, **small individual plantations can be developed** with the support from the program in the furniture of tree seedlings, as INCAJU is doing now with cashew tree seedlings. Charcoal producers can manage this type of plantations as a complementary economic activity. Agroforestry fields are also an option if N-fixing species are chosen (*Acacia* for example) to combine energy and agricultural productions on the same plot - rotation of agricultural production followed by tree growing on several fields. Agroforestry, if well managed, can significantly improve yields while adding economic revenues from energetic production. This would require training and monitoring from an extension team and diffusion of simple business plans to demonstrate the economic interest of such an alternative. Again, for the development of this type of activity, it is necessary to work with charcoal producers in order to target the agents of deforestation/degradation who will modify their impact on natural forests.

With some hypothesis of plantations annual growth, it is possible to give a first approximate assessment of the area of plantations that is necessary to meet the main cities' needs for charcoal (cf. Table 32). Giving a plantation of *Acacia* or *Eucalyptus* with average growth rate of 12 m^3/ha/yr, low wood density of 0.6, kiln yields of 25% and a management with rotations of 8 years, **it would be necessary to introduce 15 000 ha of plantations on the overall program area**. If 8 ha of plantations - to allow the production of charcoal with 1 ha/yr with rotations of 8 years - are attributed to each current producer (about 2 923 – cf. Table 33), the surface of plantations would satisfy this level.

2.3.2. Charcoal briquettes

Charcoal briquettes can be made from other sources than wood to reduce the pressure on natural forest. Crop residues or tall dry savanna grass can be used at the appropriate season, as well as charcoal fines. For crop residues or savanna grass, the process includes a carbonization phase requiring a good control of duration and temperature. Afterwards, carbonized elements are compacted and dried to form briquettes that can be easily transported and sold – this also applies to charcoal fines. Small materials (drums, small compactor) that can be easily obtained at relatively low costs are needed.

Figure 72: Several steps of the production of charcoal briquettes from dry savanna grass[14]

The change of biomass source to produce charcoal is particularly adapted to areas where forest cover is decreasing, as it is in Ilé and Alto Molocué districts. Indeed, even if the necessary materials are low costs, biomass collection work time (for savanna dry matter) and production costs are higher than for traditional charcoal production with biomass from trees - which are usually free of access in the program area except in Ilé district (see previous section). Hence, the economic feasibility of such an option is only obtained in areas where charcoal producers are limited in their access to wood resources and where charcoal prices are high. **This alternative could therefore be tested in Ilé district** as a first step, with the furniture of materials by the program to implement the technique, with a pilot group of charcoal makers. If the results are positive, the diffusion of this practice would require a

[14] From http://www.nebeday.org/p/charbon-de-paille.html

team of proximity trainers to be formed and economic incentives for primary investments, - such as small loans or material donation – to be launched by the program.

Yet, production of briquettes from charcoal fines on production areas – with charcoal part that are too small to be put in bags – or on market areas – with charcoal parts that cannot be sold – is more easily implemented as the product for compaction is already available. The additional workload - which is less difficult than cutting trees for additional production - will be compensated by additional incomes for producers (or retailers). This would only imply a training – which will also prove the value of the technique - and adequate materials that can be obtained with a loan. At the meantime, it would be necessary to raise awareness of the importance of briquettes' good calorific quality to guarantee commercial outlets.

2.3.3. Assisted natural regeneration

Assisted natural regeneration (ANR) by human intervention enables to restore natural forest cover after ancient or recent cut. Hence, it can be implemented just after "slash and burn" agriculture or charcoal production or, under certain conditions, on savannas, in order to reforest areas that were deforested years ago. This regeneration can be enhanced with enrichment in tree species or not. The technique can therefore achieve the same objectives as a "classic" energetic plantation but with lower growing rates. **ANR activity has the benefits of limiting the costs of intervention and of contributing to the conservation of the natural forest cover – and, ultimately, of tree biodiversity**.

Two main approaches can guide ANR:

- *The management of forested fallows* - in areas slashed for the production of charcoal when the deforested land is not valorized for agriculture - in order (i) to ensure natural regeneration after production and (ii) to prevent destruction by fire of seedlings and coppices of the regenerating trees.
- *The protection of savanna areas from fire and plantation of Miombo trees,* to enrich the regenerating areas, in order to reforest areas with natural cover and therefore extend the actual forest cover. New forest areas can then be used for agriculture purposes, charcoal and timber production if production sustainability is ensured by relevant management plans.

With regards to the first ANR approach, the objective is to take advantage of the number capacity of Miombo forest trees to coppice after section (Séleck et al. In prep) and to ensure the sustainability of the regeneration process, by preventing fires from occurring in the area (Peltier et al. 2012). Indeed, although fires can be necessary to maintain a certain biodiversity in Miombo forests, seedlings cannot survive to frequent and intense fires (Ryan and William 2011) - yearly fires being too frequent. A plot under ANR management may be enriched in specific forests tree species that can be worthwhile for local population, for example with species used for wood-fuel production (*Brachystegia spiciformis, Brachystegia Boehmii, Julbernardia globiflora*…), for fruit harvest (*Annona senegalensis, Scelrocarya birrea, Combretum zeyheri*…), for soil fertility (N-fixing species) or for timber (*Jambire*, *Umbila*, *Pau ferro* being the most exploited species by forest concessionaires). The development of such ANR activities would require trainings of charcoal producers (i) on cutting techniques to favor coppicing and (ii) on fire management. This will be time consuming for charcoal producers and capacity building on the value of preserving resources next to habitations would be necessary. In addition, some Payment for Ecosystem Services (PES) scheme could be implemented to offer financial incentives to charcoal producers. However, this would require continuous funding along the program period from carbon credits sales, or others, as well as a monitoring system to be handled by the program management team.

The second ANR approach has been effective in central Africa, in areas close to humid forests, but no references show any results for Mozambique or for the Miombo forest. However, the analysis of ancient maps of the Zambézia province, in comparison to actual forest distribution, suggests that relatively high regeneration dynamics occurred in parallel to deforestation dynamics in the region. The presence of cashew trees in natural forest is also an indicator of this regeneration dynamics. **This capacity of the Miombo forest can be taken as an advantage to restore forest cover on degraded areas through the protection from fire of plots located at the edge of the forest**[15] – near seed trees. This would be implemented on areas where forest cover has decreased, as in Alto Molocué and Ilé, or in areas with large portion of savannah with relatively manageable human pressure, as in the south of the GNR. This area would be interesting for testing ANR as "slash and burn" agriculture and charcoal production are practiced on a small fringe of remaining forest located between the GNR and the savannas that are separating the forest from the coastline. The population increase in those areas will require additional natural forest areas: ANR can contribute to restore forest cover at its previous extension (this area was characterized by high deforestation rates between 1990 and 2005 due to population migration). However, benefits would not be immediate – forest recovery will take 5 to 10 years; consequently, it may be necessary to provide financial incentives through a PES scheme. Moreover, to ensure the sustainable use of forest after restoration, ANR has to be completed by land use management plans – that will also contribute to resolve some raising questions about land tenure.

15 Recommendations are to introduce fire breaks around restoration plots. They are areas of usually 3m large where soil is bare (and can be ploughed) or where fire resistant culture can be settled as cassava

Mangroves' restoration, through replanting mangrove tree seedlings after charcoal production, is also an option. This type of activity is already implement in the ZILMP area by a project led by WWF. High regeneration dynamics on those areas have been confirmed by the observed low deforestation rates in the present study – thanks to regeneration no changes are observed in this ecosystem cover – and by the study of Shapiro et al. (2015) in the Zambezi delta. They argue for of a low intervention. However, deforestation rates of mangroves have to be monitored: if they increase, restoration strategies of this high carbon stocks and biodiversity ecosystem would have to be implemented in the ZILMP area.
Plantations and ANR in savannas also have the benefit of sequestering carbon - a property that can be accounted for and valorized in the ZILMP program. This would generate additional carbon credits that can be mobilized to fund such activities. In this case, a special monitoring system will have to be developed for afforestation and reforestation. For this type of activity, a proxy based system can be relevant, as sequestration factor can easily be developed for the program area, based on the most common species and then combined with declaration of plantations areas – areas that will serve as proxy for performance based payment.

3. Land planning

According to the ER-PIN, there is a specific challenge for the implementation of the ZILMP linked to land planning and tenure rights. For the ER-PIN, although the land law is very progressive, it still depends on the government's (financial) capacity to put it into practice. The process of obtaining the Land Use Right Certificate (DUAT) is very bureaucratic and time-consuming, resulting in high, frequently prohibitive, transaction costs. In consequence, the ER-PIN says that to increase the cost efficiency of REDD+, it will be important to implement a rural land registry and to adopt simpler and faster processes to obtain community and individual land titles (DUATs).

In the ER-PIN, that idea entails two types of activities, budgeted for more than 7.5 MUSD:

- The development and implementation of district development plans.
- The land registration of farmers and communities.

We agree on the weakness of the land allocation process and on the long-term importance of land planing activities, yet we do not see this option as being a priority in terms of deforestation mitigation, for various reasons.

There is hardly no land conflicts

Today, **land pressure is relatively low** and conflicts over access to this resource are not a major issue in the ZILMP area. The traditional land management is quite simple: families settle in a diffuse way, without centralised decision; this is similar to other regions where land is not a constraint. Moreover, there are very few large-scale agriculture projects.

Plans already exist, districal administration is weak and other sectors should be prioritised for law enforcement

Plans already exist, including:

- Plano Distrital de Uso da Terra (PDUT) - each of the former 5 districts has its own;
- Agro-ecological zoning;
- Plano Provincial de Desenvolvimento Teritorial (PPDT)…

In the ZILMP area, PDUT do not seem to be enforced. It is even very difficult to find an official who knows where the PDUT is. Unfortunately, districal administration is very weak. Although improving efficiency in the public service is essential, it does not appear as a priority for a REDD+ program to initiate a new zoning – land planing activity at the district level: it will be lengthy and costly for an unknown impact.

If actions have to be launched in zoning – land planning, we would suggest to focus the work at provincial level, on the coordination of the different existing geographic database: the DUAT registry, the forest concession registry and the mining cadaster, into a unique transparent plateform.
Districal administration should be used for field work such as forest law enforcement or agricultural extension.

Land security does not always mean investment in land-intensification

The underlying assumption for promoting farmers' land certification is that **securing their rights will allow them to invest more in the development of their** land and thus increase the added-value per hectare. **In our opinion, this assumption is not valid for the ZILMP area**. As seen before, in areas where labor is more limited than land in relative terms, extensification is the most rational strategy for smallholders. Intensification usually only occurs during crises of land shortage. **Therefore, even with a land title, smallholders will not stop to deforest.**

The main challenge of the program is the dissemination of new practices tailored to smallholders strategies. It requires applied research within smallholdings and intense personalizaded technical support. This approach is expensive; in our opinion, it seems more appropriate to earmark available funds for that kind of action.

4. Forest management and conservation areas

Emissions from forest degradation due to legal and illegal logging only represent 1.1% of the total deforestation emissions, therefore the ZILMP could decide not to account for those emissions and not to enter in any activities linked to the mitigation of this type of degradation. As it seems very difficult to tackle this problem, it may be an efficient decision.

Nevertheless, we tried to examine some options to reduce degradation from logging.

4.1. Illegal logging

Limiting emissions from forestry consists mainly in limiting illegal logging, which is the main source of wood in the country. Currently, there is a strong political will to reform the forest sector, with the recent endorsement of a new policy package including law enforcement elements, *inter alia*:

- Review of all forest operators in Mozambique.
- Moratorium from the 1st of January 2016 on the attribution of new concessions and licenses.
- Moratorium from the 1st of January 2016 on *pau-ferro* harvesting.
- Moratorium from the 1st of January 2016 on exportation of unprocessed logs, whatever the wood type.

Whereas we recognize the political will behind this package, we have doubt about its efficiency in reducing illegal logging. Indeed, today, 93% of the harvested wood is considered illegal (EIA 2014); the new package is extending the domain of illegality but does not change anything on the root of illegality and the easiness of being illegal.

Falcão (2015) has already calculated the cost – benefit ratio of corrupting officers versus legality, and demonstrated that corrupting officers where 5 times more profitable than being legal - without even taking into account the huge transaction cost of being legal. According to us, even if an officer were incorruptible, **there would hardly be any cost in being illegal, making illegal forestry a non-risky activity**.

Today, for instance, the classic illegal scheme around the GNR is as follows: illegal loggers pay between 20,000 and 40,000 meticais to community members to gather *pau-ferro* from within the GNR and fill-up a whole truck; if the truck is caught by a serious officer, loggers are fined up to 1,000,000 - 2,000,000 meticais. Nevertheless, they pay a first advance of 100,000 meticais at provincial level and get an authorization to get their truck back; on the day after, the same truck may be involved in illegal activities and the rest of the fine will never be paid. To sum up, it costs no more than 300 USD to be caught in illegal activities.

An effective policy package to combat illegal logging should aim at modifying the cost – benefit ratio of being illegal. Being illegal should be risky or at least it should be costly for the offender.

There are different ways to increase the cost of illegality:

- Impede restitution of trucks before total payment of amends.
- Retain truck drivers.
- **Destroy trucks, machines and arms caught in illegal logging activities** (as it is done for ivory trade).

On the review of forest operators, Mackenzie (2006) proposed to also include in the review process the forestry administration, in order to identify corrupt practices and root out corrupt officers, initiated through a detailed investigation and enquiry into forest practices.

4.2. Conservation areas

Today, although there is no deforestation in the GNR, the Reserve is endangered in certain specific places such as Namurrua, in the northeast.

As already seen in the agriculture section of this study, in areas where labor is more limited than land in relative terms, extensification is the most rational strategy for smallholders. Intensification usually only occurs during crises of land shortage. The GNR plays an important role in terms of land tenure and its role should be reinstated. The GNR administration should not allow any installation within the Reserve. **We could consider physical delimitation of the Reserve in areas where deforestation for agriculture may occur**.

The GNR staff is very efficient in combatting illegal logging in the Reserve, nevertheless, after fining an offender, most of the legal work takes place in the province capital, Quelimane, and the Reserve itself does not have the means to follow-up those processes. **The GNR should have legal support in Quelimane to help follow up legal issues and prevent its fieldwork to be undermined**.

5. Summary on options to reduce deforestation and forest degradation

Major shift in budgeting towards AC extension and increase of revenue generation through cash crops

	Technical feasibility	Social feasibility	Economic feasibility	Deforestation and forest degradation mitigation potential	Extension models	Conclusion
Agro-ecology intensification and increased revenue through cash crops						
Support to agro-ecology intensification, mainly on maize and cassava crops	The main "good practices" are known, but need modulation according to smallholders and *in-situ* test	Agro-ecology practices to be proposed should be low-labor intensive	Need to be based on low cost inputs	High, as maize and cassava almost are the unique drivers of deforestation	Individual support Small number of smallholders per extension agents Well trained extension agents needed	First priority Budget Consuming
Increasing smallholders income						
Support cash crops production	Main focus on cashew (3/7 districts) and sesame seed (4/7). Second focus on beans and groundnuts	Annual cash crop: Easy to Implement Cashew: more intensive training needed	Should increase income but depends on world market prices	Indirect, as increased incomes ease the endorsement of good practices	Standardized extension is possible	Priority Moderately budget consuming
Support crops marketing	Focus on sesame and cashew	Important need to improve	Will increase smallholders'	Indirect, as increased incomes	Standardized extension is possible.	Priority

	Technical feasibility	Social feasibility	Economic feasibility	Deforestation and forest degradation mitigation potential	Extension models	Conclusion
		smallholders' marketing skills	income	ease the endorsement of good practices	Use of ICT (SMS)	Low budget consuming
Promote no-deforestation value chains	Focus on sesame and cashew Need to elaborate a balanced contract farming scheme		Need for long-term involvement of an international buyer	High Allow to link increased income to agro-ecology intensification	Mix of standardized and personalized extension model	Priority
Post-harvesting value-added	Depends on commodity. See below for some examples			Indirect, as increased incomes ease the endorsement of good practices		Priority. Through a call for proposal for micro-project
Cashew			Cashew: small scale processing is not sustainable			
Cassava	Limited options for processing (high quality cassava flour)		Low local demand for processed cassava			
Mango	Fresh mango: need for high logistical skills Dried mango: Easy to Implement		Fresh mango: Highly competitive international market Dried mango: over supplied			No call for proposal (From the ER-PIN)

	Technical feasibility	Social feasibility	Economic feasibility	Deforestation and forest degradation mitigation potential	Extension models	Conclusion
			international market			
Agricultural land development	Focus on highly deforested district (Ilé & Alto-Molocué)	Labor constraints should be assessed	Need to be based on low cost inputs	Medium All land intensification		Priority. Through a call for proposal for micro-project
Infrastructure and logistics for storage	No particular needs in storage infrastructure					Not a priority (From the ER-PIN)
Improved kilns for charcoal production						
Training of charcoal producer groups for the construction of improved kilns	Current techniques to be assessed and creation of a training manual	Monitoring time need to be low	Need to be based on low investments – kilns will continue to be made from soil	Low – Medium Yields will only be slightly improved Improvement of charcoal producers' revenues	Group of proximity trainers – specialists in carbonization techniques	Medium priority Highly demanding on human resources for training and monitoring
Improved cookstoves for charcoal						
Training of cookstoves producers to constructions of improved cookstoves	Identification of the necessary materials Training sessions for groups in each cities	Diffusion of the economic interest of those cookstoves in market places	Proposition of small loans for households	Low Small reduction of monthly consumption of charcoal	Punctual mobilization of trainers	Not a priority Low costs Low human resources
Implantation of small industry to	Need to identify a private partner	Employment creation	Need to be assessed – manufacture	Low Small reduction of	Proposition via a call for proposals	Need a feasibility Assessment -

	Technical feasibility	Social feasibility	Economic feasibility	Deforestation and forest degradation mitigation potential	Extension models	Conclusion
manufacture improved cookstoves			probably based in Quelimane or Nampula	monthly consumption of charcoal	Loans to start the industry	Economic risks
Development of other sources of energy						
Improvement of the electricity network	Managed by the government according to development strategy	Need of improved revenues to buy adapted cookstoves – proposition of small loans		High reduction of charcoal production if households move forwards electric stoves for cooking		
Training of cookstoves producers for the construction of solar cooker	Identification of the necessary materials – training sessions for groups in each city	Diffusion of the economic interest of those cookers in market places	Proposition of small loans for households	Low Small reduction of monthly consumption of charcoal	Punctual mobilization of trainers	Not a priority Low costs Low human resources
Plantations						
Development of industrial plantations and carbonization kilns	Identification of a private partner	Employment creation	Feasibility assessment according to local charcoal consumptions need	Medium Replacement of natural resources by plantations	Charcoal producers have to be targeted as employees	Needs a feasibility assessment - Economic risks
Development of small individual energetic plantations or agroforestry	Creation of nurseries and distribution of seedlings according to the INCAJU model – need for specific	Higher work time but can serve as a capitalization system if completed by land tenure clarification	Necessity to diffuse simple business plan	High Replacement of natural resources by plantations	Charcoal producers have to be targeted High mobilization of trainers team for	Medium priority Highly demanding on human resources for trainings and

	Technical feasibility	Social feasibility	Economic feasibility	Deforestation and forest degradation mitigation potential	Extension models	Conclusion
	trainings	Double benefits if located in agroforestry systems		The location of plantations has to be relevant, according to natural vegetation – on city surroundings	trainings and monitoring	monitoring
Development of techniques to produce briquettes from charcoal fines	Identification of the necessary materials – training sessions for groups in each supply basin	Higher work time: needs to be assessed in comparison to additional incomes Promotion of the value of briquettes to consumers	Low investments to be assessed with regards to higher income	Low Slight improvement of charcoal production with the same quantity of biomass	Punctual mobilization of trainers	Local feasibility to be assessed around each city Low costs
Development of techniques to produce briquettes from crop residues or savanna dry grass	Identification of the necessary materials – training sessions for groups in supply basin with low forest cover	Higher work time: needs to be assessed in comparison to incomes Promotion of the value of briquettes to consumers	Low investments to be assessed with regards to incomes Study on the supply value chain to be created	Medium Charcoal production with other sources of biomass Current charcoal producers to be targeted	Punctual mobilization of trainers	Local feasibility to be assessed around Ilé and Alto Molocué Low costs
Assisted natural regeneration						
Assistance and monitoring of	Trainings sessions of charcoal producers	Higher work time for charcoal producers –	No investments	Medium It will favor forest	High mobilization of extension team for	Priority Focus on high

	Technical feasibility	Social feasibility	Economic feasibility	Deforestation and forest degradation mitigation potential	Extension models	Conclusion
regeneration after charcoal production by charcoal makers	groups and monitoring	possible necessity of incentives Probably more adapted to areas with low forest cover		regeneration and, by doing so, maintain forest cover in the long term	trainings and monitoring High awareness on the interest of forest regeneration	production areas such as Ilé and Alto Molocué
Planning and registration						
District land development plans	Easy to draft, Hard to implement			Very low		Not a priority (From the ER-PIN)
Land and farmers registration program			Land security will not drive agricultural intensification	Low		Not a priority (From the ER-PIN)

Institutional arrangements for the implementation of the REDD+ program

This section aims to propose institutional arrangements for the implementation of the options that were suggested in the former section.

First, as explained before, deforestation and forest degradation in the ZILMP area are nearly exclusively due to smallholders' business, as usual activities: "slash and burn" agriculture and charcoal production. Because they are subsistence activities, modifying those practices is a great challenge. It will require intense fieldwork and a subsequently large number of extension agents. Respective efforts will have to be coordinated; institutional arrangements have a key role to play for this matter.

As institutional arrangements considerations may sometimes be very theoretical, we tried to be as pragmatic as possible and to propose, as far as we could, concrete recommendations.

It should be noticed that this report addresses institutional arrangements for the implementation of the ZILMP program; it does not address the national REDD+ strategy as a whole.

1. Methodology

Our report is based on literature review on best practices concerning jurisdictional REDD+ program and on interviews with key stakeholders.

Since jurisdictional approaches are still new, there are only few feedbacks on their implementation. Nevertheless, two key resources emerged from our bibliography review:

- The WWF Guide to building REDD+ strategies (WWF 2013) that entails 7 core functions to be considered for the design of implementation arrangements.
- Early lessons from jurisdictional REDD+ and Low Emissions Development Programs (Fishbein and Lee 2015).

2. Recommendations for the ZILMP implementation

We tried to avoid general considerations as much as we could and rather decided to submit *ad-hoc* proposals fitted for the ZILMP implementation.

2.1. At which level should the ZILMP be managed?

2.1.1. Context

In June 2015, UT-REDD+ hired **a provincial coordinator** (Thomas Bastique) to carry on the preparation, consultation process and implementation of the program's early activities – that is, between 2015 and 2016. The provincial coordinator is placed with the Provincial Directorate for Land, Environment and Rural Development (Direção Provincial Terras, Ambiente e Desenvolvimento Rural, DPTADER).

A Provincial REDD+ Forum with local institutions and stakeholders is also operational. It is in charge of ensuring consistency in the implementation of REDD+ between national and subnational levels, as stated in the ER-PIN (UT-REDD 2015).

The study conducted on the national legal and institutional framework for REDD+ (BETA e NEMUS 2015) suggests to continue with the current pilot arrangement and to maintain the ZILMP coordinator with the DPTADER.

We are offering a different arrangement.

2.1.2. Proposal & rationale

According to the ER-PIN, inter-institutional and sectorial collaboration is very weak in the program area. This situation favors illegal logging and unplanned land occupation. We share this observation; worse, we have witnessed a similar lack of coordination within the very same departments: it was true, for instance, for the Forestry Service (*Serviço Provincial Floresta e Fauna Bravia*, SPFFB) and the Land Registry Office (*Serviço Provincial Geografia e Cadastro,* SPGC), which are both part of the DPTADER, for sharing geographical database.

This coordination is even less effective between distinct departments: Land & Environment, Agriculture, Mines and Infrastructure. Even though the nearly unique driver of deforestation is smallholders' production of maize and cassava and the core activity to be implemented is large-scale extension of agro-ecology intensification, REDD+ program still largely remains a forest-sector driven program. This has to be changed to ensure good implementation of the ZILMP.

Mitigating deforestation in the ZILMP area is not a problem of Natural Resource Management Policy but of Agricultural Policy, implemented by the Provincial Directorate for Agriculture and Food Security (*Direcção Provincial da Agricultura e Segurança Alimentar*, DPASA) and its extension services (*Serviço de Extensão Agraria*). Unfortunately, **green development, and especially deforestation mitigation, has not yet been mainstreamed across the agricultural sector**, even though agro-ecology is already part of some public extension programs in Zambézia. **Securing DPASA's cooperation and integrating forest protection into their action is crucial.**

Moreover, today, most stakeholders acknowledge that the quality of regulatory instruments is sufficient to achieve sustainable development goals. **The political will of leaders at both**

national and subnational levels is critical to the actual implementation of those instruments. This is an absolute condition if it is decided to include the forest sector in the ZILMP.

Finally, the important turnover in the administrative services in Zambézia hinders the sustainability of **commitment for forest conservation** (for instance 4 heads of services in 6 years in the SPFFB).

For all the above reasons, **we believe that the coordination of the ZILMP program should be assigned to a dedicated team under the direct authority of the provincial governor**. It will enhance inter-sectorial and inter-institutions coordination and shows political will and sustained commitment.

For the implementation itself, **the size, level of ambition and complexity of jurisdictional approaches quickly face capacity and resource gaps**. In the case of the ZILMP, the lack of human, technical, and financial resources is particularly important. Consequently, **we recommend concentrating capacity building efforts**. According to us, the ZILMP should be managed as a whole by a single dedicated unit – as described above. Its implementation should be delegated to the provincial directorates and built on existing efficient structures that are already operating on the ground – may they be public, private or NGOs. We do not see, for instance, systematic decentralization of implementation to districts as being an effective solution. But district, on a case-by-case basis, could have some responsibilities.

This is particularly true for the agricultural extension. As already explained, it is very important to have one single method for extension, which enables individual modulation of support. Intensive training of extension agents will also be very important. Extension agents' commitment is crucial and the implementation of the program could be based on the various partners who already are present, as long as this commitment is real. The program should therefore assess the reality of this commitment, all along the program, and act accordingly. A result-based payment could be considered for the extension agents, based on the rate of adoption of new practices.

2.2. Transparency of data, Monitoring and Reporting

2.2.1. Context

Accountability, through transparency of data and information, is critical to driving change. Today, data is dispersed among many stakeholders and not shared, or in format (PDF for instance) that do not enable manipulation and crosschecking, for instance. For instance, in the SPFFB, it is not possible to get a unique spreadsheet with data on licensed wood and on the 20% return to the communities to crosscheck the amounts. This makes **law-enforcement difficult and hinders third party verification. Information is also important for efficient design**

of activities and adaptive management all along the implementation process of a REDD+ program. Finally, transparent information is essential for the ownership by all stakeholders.

2.2.2. Proposal & rationale

A web platform, which would gather information, should be created. **The first objective of this platform would be to make available and usable by all a series of up-to-date data linked to rural development:** DUATs, forest concessions, forest licenses, licensed wood, market prices for agricultural commodities, etc. It would suppose an important initial work of data gathering and, then, a sustained effort of updating linked to data producers. The platform **would also gather activities data linked to the implementation of the ZILMP**: localization of extensions parcels, localization of charcoal producers, etc. Finally, **it could also gather monitoring data on deforestation, forest degradation and carbon stocks.**

The data would be delivered through a Geographical Information System and spreadsheets. A dedicated team within the coordination unit of the ZILMP would be in charge of this platform: it would be composed of a GIS specialist and a database specialist responsible for gathering information and preparing common format for reporting by implementing partners.

This platform could be based on the one created by Etc Terra for the Gilé REDD+ pilot project and could be inspired on the *Cadastro mineiro de Moçambique*.

2.3. Possibility for contracts with stakeholders

The ZILMP will be implemented by various stakeholders. To ensure that all of them contribute effectively to the ultimate goals of the program, a contract scheme could be set-up through Memorandums of Understanding (MoU) between the coordination unit of the ZILMP and each of the implementing stakeholders.

MoUs could entail rights and duties of the implementing stakeholders, as well as associated budget. Specific provisions should be enclosed on data sharing to the common information platform. Regarding agricultural extension, a specific clause on the commitment to follow the method proposed should be included in the MoU.

2.4. Link between VCS project and Jurisdictional program

2.4.1. Context

In many countries, early REDD+ actions are being developed at different levels: projects at local level and jurisdictional programs at subnational level. These different scale initiatives are useful to test activities and to produce early results in emissions reduction. However, they usually are at different development stages and use different methodologies for the elaboration of reference emission levels, MRV systems and carbon credits trading scheme.

Ensuring compatibility between approaches is necessary to guarantee environmental integrity, avoid double counting and ensure equity between the various stakeholders who participate to the efforts for emissions reduction through the sharing of performance based payments. That is why it is necessary to develop a scheme to integrate projects into national or subnational programs through a nested approach at the early stages of development.

In Zambézia, a pilot REDD+ project, the so-called Gilé project, is currently under development and seeks to be registered under the VCS in 2016 in order to sale credit on the voluntary carbon market. The registration of the Gilé project is planned to occur well before the ERPA signature for the ZILMP program.

It is therefore necessary to anticipate (i) how the REDD Gilé project will be included in the ZILMP program, (ii) the compatibility of methodologies and (iii) how benefits can be shared.
Several components of the carbon accounting system have to be taken into consideration in a nested approach, mainly compatibility of Reference Emissions Levels (RELs) and of Monitoring, Reporting and Verification (MRV) systems. These components are summarized in the following figure.

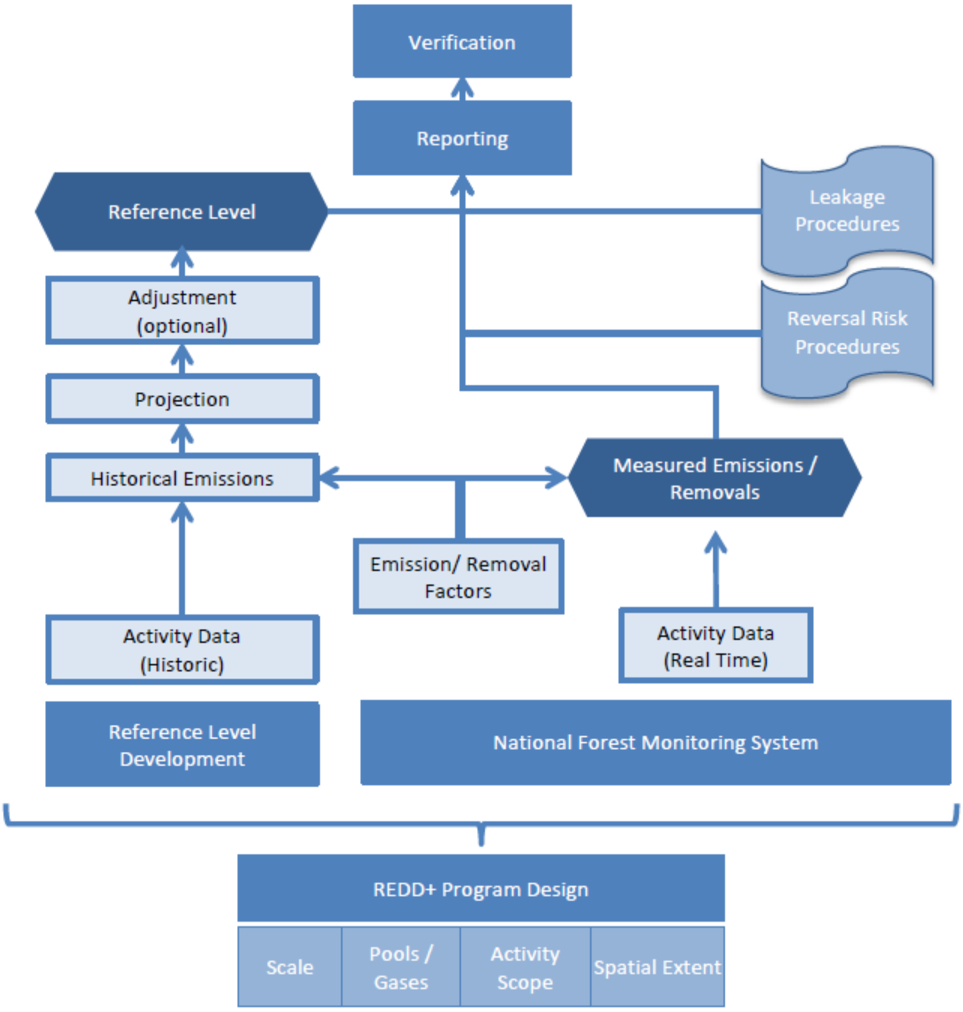


Figure 73: Components of the national or subnational carbon accounting system that would be included in a nested approach (From Broadhead et al. 2014)

3. Several possibilities for nested approach and methodological framework

Depending on the level of development of national monitoring systems, on the level of centralization of forest policy enforcement and on the existence of projects or subnational programs, the nested approach can be more or less driven by national methods or, conversely, by projects' ones, as proposed by Gibbon (Gibbon et al. 2014) (see figure below).

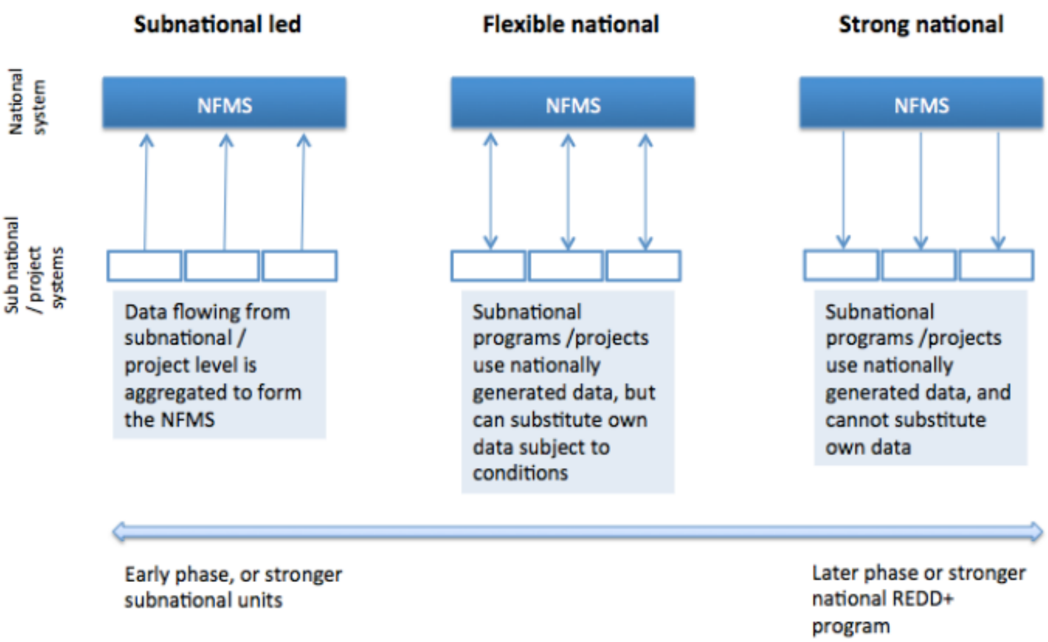


Figure 74: Several nested approaches to integrate national forest monitoring system (From Gibbon et al. 2014)

The most challenging part may be the compatibility of REL. Project level methodologies anticipate that, in case of subnational or national REL development, projects have to adapt their REL to the one of the above program during the next baseline revision (10 years at a maximum duration). To avoid too large discrepancies, several recommendations can be followed (Gibbon et al. 2014):

- Projects should use methods for their baseline that are as similar as possible to the methods that are used in the program to which they belong, if available. Projects that are developed after the validation of a program shall directly extract their REL from the program.
- Programs can integrate and aggregate projects RELs to ensure compatibility. Because project baselines are usually more detailed, it may require an early revision of project baseline if the reference periods are not the same, which can create some gaps, depending on the size of projects and programs.
- If the program REL is spatially explicit, projects can “cut-out” their REL from the more global program’s projections. The same can be done for MRV.
- If not spatially explicit, project contribution to program performance before the baseline revision can be calculated on a basis of proxies, as a combination of proportion of program area, excepted efficiency of activities, number of implemented activities, number of stakeholders, etc. Again, the same can be applied for the verification of emissions reduction.

In any case, it is important for projects and programs to consider the same carbon pools and activities (deforestation, degradation, etc). Moreover, leakage from project area to other areas of the program, and inversely, would have to be quantified to estimate performance in a rigorous way.

4. Implication for crediting and benefits sharing

The way in which projects - and especially their REL - will be included in programs is directly connected to the method that is used to measure the performance of several initiatives in the program area and to the crediting scenario. Relevant questions are: (i) will projects performance be measured through the analysis of deforestation areas against extraction of program baseline (if spatially explicit) or (ii) will the program use proxy of implemented actions to evaluate their contributions to the program?

Those two options entail different implications in terms of implementation costs and technical expertise. In addition, they may have an impact on possible crediting scenarios. As suggested by the Jurisdictional and Nested REDD+ requirements of the VCS standards (VCS 2012), the program can choose several options for the crediting of nested projects (Figure 75): it can decide that crediting can only occur with the jurisdiction or that two crediting schemes can coexist - jurisdiction with its buyers and projects with other buyers of the voluntary market. The second case requires that project also validate a PDD in order to be recognized by the program. To avoid double counting of emission reduction, this option is not compatible with proxy measurement of performance and, globally, it does not participate to lower transaction costs - but it can be more appealing for early projects or private sector that wants to target different kinds of buyers. However, those options can be adapted to various projects according to their particular constraints.

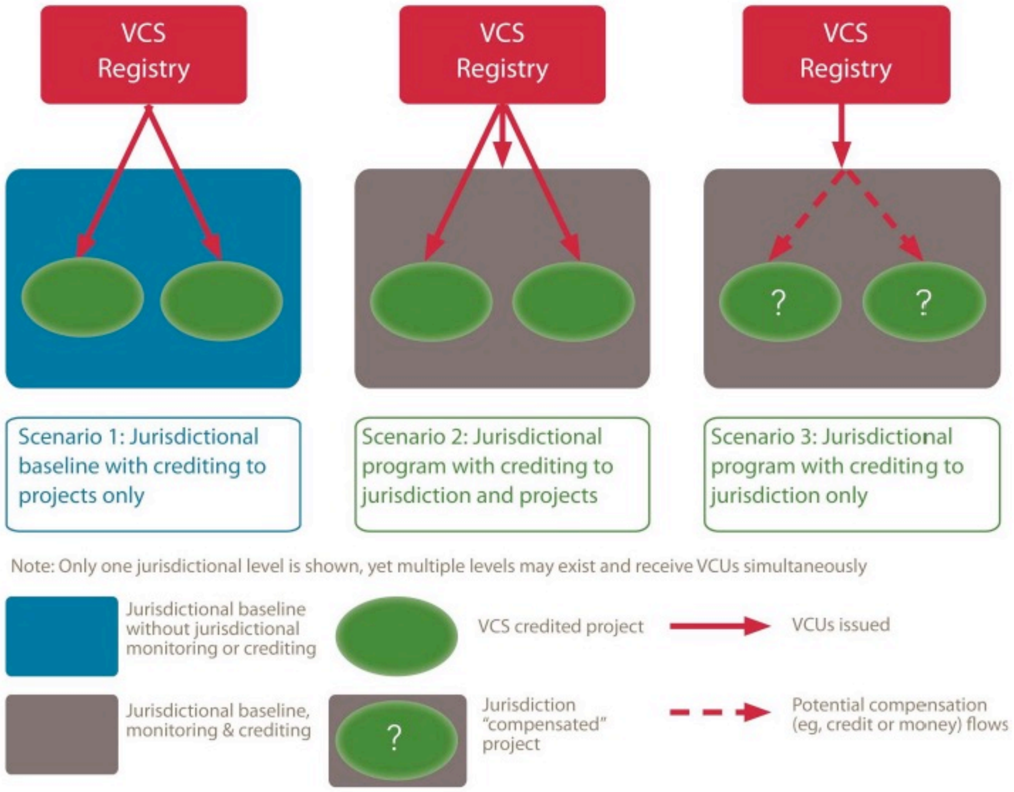


Figure 75: Several crediting scenario proposed by VCS standard (From VCS 2012)

2.4.2. Recommendations:

To the government concerning the Gilé project:

- Facilitate the validation of the VCS project, in order to valorize early efforts and to avoid dependency on the ZILMP success to ensure sustainable funding of the Reserve through the sale of carbon credits.
- Urge project developers to adopt a REL that is as similar as possible to the ZILMP one.

To the Government concerning the ZILMP program:

- Adopt a flexible approach. Since the Zambézia program chooses to use a spatially explicit approach for the REL, it will be possible for other projects to extract their REL from the program's one.
- As the Gilé REDD+ project will probably register to VCS before validation of the program, it would be interesting (i) to direct the program to a crediting scenario that would be similar to the second one proposed by VCS JNR and (ii) to measure performance with a spatially explicit analysis of deforestation, trough remote sensing techniques (the size of the program is coherent with wall to wall regular analysis). This would foster the adaptation or elaboration of REL for potential other projects and guarantee transparency and objectivity of performance evaluation.

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Annexes

Annex 1: Confusion matrix calculations

A confusion matrix is a table providing for classification accuracy statistics, such as percentages of omission or commission for each classe. This matrix is created by comparing classified data (row) with the reference data after photo-interpretation (column), the values therein being pixel, numbers or objects.

Table 49: Presentation of a confusion matrix and its rules

		Classes observed by photo-interpretation (control plots)			
	Classes	1	i	n	
Classes predicted by the algorithm (Map)	1	M(1,1)	M(1,i)	M(1,n)	M(1,+)
	I	M(i,1)	M(i,i)	M(i,n)	M(i,+)
	N	M(n,1)	M(n,i)	M(n,n)	M(n,+)
	Classified	M(+,1)	M(+,i)	M(+,n)	$T_{classified}$
	Non-classified	M(x,1)	M(x,i)	M(x,n)	$T_{non\text{-}classified}$
	Total	T(1)	T(i)	T(n)	T

Where
T total number of sampled pixels, all classes considered
T(i) total number of class i pixels
$T_{classified}$ total number of classified pixels, all classes considered
M(i,i) number of class i pixels classified correctly
M(i,j) with $i \neq j$ pixels from the sample incorrectly affected (commission error)
M(x,i) unclassified class i pixels (omission error)
M(i,+) marginal value of row i (row sum)
M(+,i) total number of classified pixels that are photo-interpreted as belonging to class i

From this confusion matrix, different indexes can be calculated to assess the quality of the classification:

1. Overall accuracy of the classification.
2. Kappa index.
3. Omission error (producer accuracy).
4. Commission error (user accuracy).

Overall accuracy and Kappa index

The overall accuracy of a classification (G_0) is the ratio between the number of accurately classified pixels (M(i,i) (diagonal elements of the confusion matrix) and the total number of sampled pixels (T).

$$G_0 = \frac{\sum M(i,i)}{T}$$

The Kappa index, suggested by Cohen (1960), is another index for assessing the quality of a supervised classification. It is mainly sensitive to errors linked the algorithm. It is calculated thanks to the following formula:

$$Kappa = \frac{(T_{classés})\sum M(i,i) - \sum\left[M(i,+).M(+,i)\right]}{(T_{classés})^2 - \sum\left[M(i,+).M(+,i)\right]}$$

A Kappa index close to 0 means that the algorithm is close to a random classifier. On the contrary, a Kappa index close to 1 indicates a nearly perfect classification (Congalton 1991).

Quality indexes per class

The commission error (EC) gives an indication on the homogeneity of each class.

$$EC = 1 - \frac{M(i,j)}{M\ (i,+)}$$

The omission error assesses the performance of the classification algorithm.

$$EO = 1 - \frac{M(i,j)}{M\ (+,i)}$$

Annex 2: Example of weighted deforestation rate calculation

The example below shows the subsequent steps to calculate a weighted deforestation rate.

Figure 76*:* Intersection of the program area layer and the 'date of tile' layer

Table 50*:* Example of deforestation rates calculation

	Tiles date			Time intervals [year]		Forest area [ha]		
Path_row	**date1**	**date2**	**date3**	**I1**	**I2**	**A1**	**A2**	**A3**
165_072	09/03/2005	10/05/2010	02/03/2014	5,17	3.81	225,935.73	225,311.13	225,006
165_071	09/03/2005	10/05/2010	02/03/2014	5,17	3.81	161,807.94	160,870.05	159,424.11
					Total	**387,744**	**386,181**	**384,431**

	Weighting coefficient		Annual deforestation rate [%/year]		Weighted intervals over the two periods		Weighted annual deforestation rate [%/year]	
	ω1	**ω2**	**Θ1**	**Θ2**	**ω1*I1**	**ω2*I2**	**ω1*Θ1**	**ω2*Θ2**
165_072	0.58	0.58	0.05	0.03	3.01	2.22	0.031	0.02
165_071	0.42	0.42	0.11	0.17	2.15	1.58	0.034	0.07
				Total	5.17	3.81	**0.06**	**0.09**

Annex 3: Choice of an allometric equation

There are very few allometric equations that are specific to Mozambique.

Recently, Mate produced three equations (Mate, Johansson, and Sitoe 2014) (Mate, Johansson, and Sitoe 2015) but they are species-specific for *Pterocarpus angolensis* (Umbila), *Afzelia quanzensis* (Chanfuta) and *Millettia stuhlmannii* (Jambire).

A few non-species specific equations were devised, including by Sitoe (Almeida Sitoe et al. 2001). However, its accuracy may be limited by the small sample of harvested trees that was used for its calibration (n = 12). Tchauque created another equation (Tchauque 2004) that was built on a much larger sample (n = 290). Nevertheless, we decided not to use it as trees that were harvested for calibration had diameters ranging from only 5 to 45 cm, whereas the diameters of the trees of the ZILMP inventory ranged up to 99 cm. Moreover, the tree sampled did not only come from Miombo forest ecosystems but also from thickets, open bushes and savannahs with trees.

We found a non-species specific equation for Miombo forest in the neighboring country of Zambia. It was produced by Chidumayo (Chidumayo and Stockholm Environment Institute. 1997). We considered that this equation clearly underestimated biomass for large diameters (see Figure 77).

Given this, we looked at global equations that were calibrated on a very large number of trees, like the one produced by Chave (Chave et al. 2005) for dry tropical forests (n = 2410).

Chave produced a new equation in 2014 (Figure 77), which was based on a higher number of sample trees (n = 4004) and entailed some data from Africa - including from Mozambique (Chave et al. 2014). This equation, which is more accurate than the 2005 equation, can be used for all types of forest.

Table 51: Non-species specific allometric equation studied

$\langle AGB \rangle_{est} = -31.5 - 2 \times \mathrm{D} + 0.91 \times \mathrm{D}^2$	(Almeida Sitoe et al. 2001)
$\langle AGB \rangle_{est} = -41.077 + 2.816554 \times D + 0.35657 \times D^2$	(Tchauque 2004)
$\langle AGB \rangle_{est} = 20.02 \times D - 203.37$	(Chidumayo and Stockholm Environment Institute. 1997)
$\langle AGB \rangle_{est} = \exp(-2.187 + 0.916 \times \ln(\rho D^2 H))$	(J. Chave et al. 2005)
$\langle AGB \rangle_{est} = 0.0673 \times (\rho D^2 H)^{0.976}$	(Jérôme Chave et al. 2014)

Where AGB is aboveground biomass, ρ wood density, D tree diameter and H tree height.

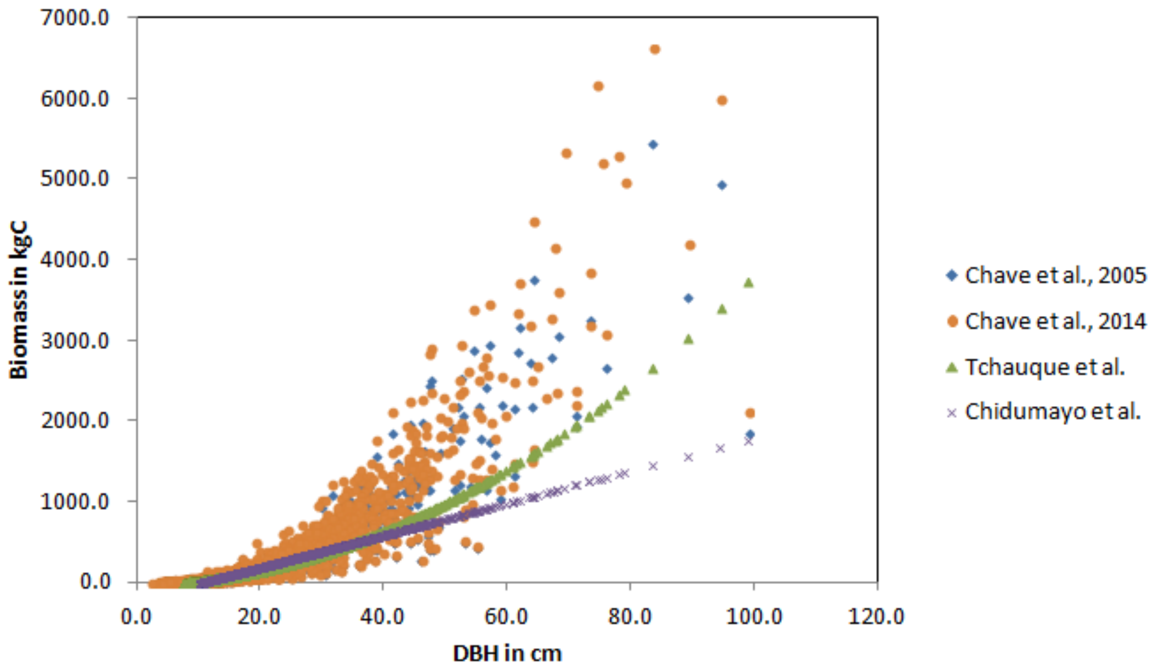


Figure 77: Comparison of the results from different allometric equations available for the study of carbon stocks in Miombo forests

Annex 4: Survey method for charcoal value chain analysis

The charcoal value chain was analyzed thanks to a survey that was conducted in more than 5 districts of the program area, on charcoal supply basins of the 5 main cities. It was completed by observations related to the various roads of the area, since they also constitute attractive factors for charcoal production and selling. For each survey area, enquiries focused on the two extreme parts of the value chain – upstream to downstream - as follows:

- Consumers were interrogated in city charcoal markets. A small inquiry was used to assess the quantity of charcoal that is consumed by each household. From estimates on the number of inhabitants in each city and on the proportion of consumers, total quantity consumed and, therefore, produced, could be assessed.
    - 400 questionnaires of this inquiry were conducted.
    - The prices of charcoal were also collected on markets.
- Inquiries in local administration were realized to obtain estimates on population in each city and to know the neighborhoods where charcoal is consumed.
- Producers were also interrogated in supply basins to better know their production techniques, the frequency and the location of their productions. Several villages were targeted on each supply basins to guarantee the representativeness of the survey. Villages were identified according to the provenance of charcoal intermediaries on markets. This part enabled us to assess the number of producers (in combination with the total quantity of charcoal consumed) and the factors influencing the location of charcoal production. Moreover, it provided for indications on selling prices. This will be helpful to identify places where charcoal producers should be targeted for the implementing phase of the ER program.
    - 101 questionnaires of this type were conducted. The villages that were visited during the enquiry are listed on Figure 78.
    - The questions from PPI[16] (Progress out Poverty Index) were asked to all interviewed producers, in order to draw up a reference database of the indicator. Its monitoring will be planned in order to assess the evolution of poverty level of several populations involved in the program.
- Those enquiries were completed with non directive interviews of several actors of the value chain:
    - 29 producers, in order to improve knowledge about their techniques and the issues they are facing.
    - 9 local leaders, in order to obtain information about land tenure distribution and local dynamics of population and charcoal production.
    - 7 consumers, in order to understand how they choose charcoal.

[16] Developped by the Grameen Foundation: http://www.progressoutofpoverty.org/

- 6 intermediaries, in order to assess the necessary time of work and margin of this activity.

The questionnaires that were used and the database that was produced are available on demand. The survey was conducted between July and November 2015 by local staff of Etc Terra.

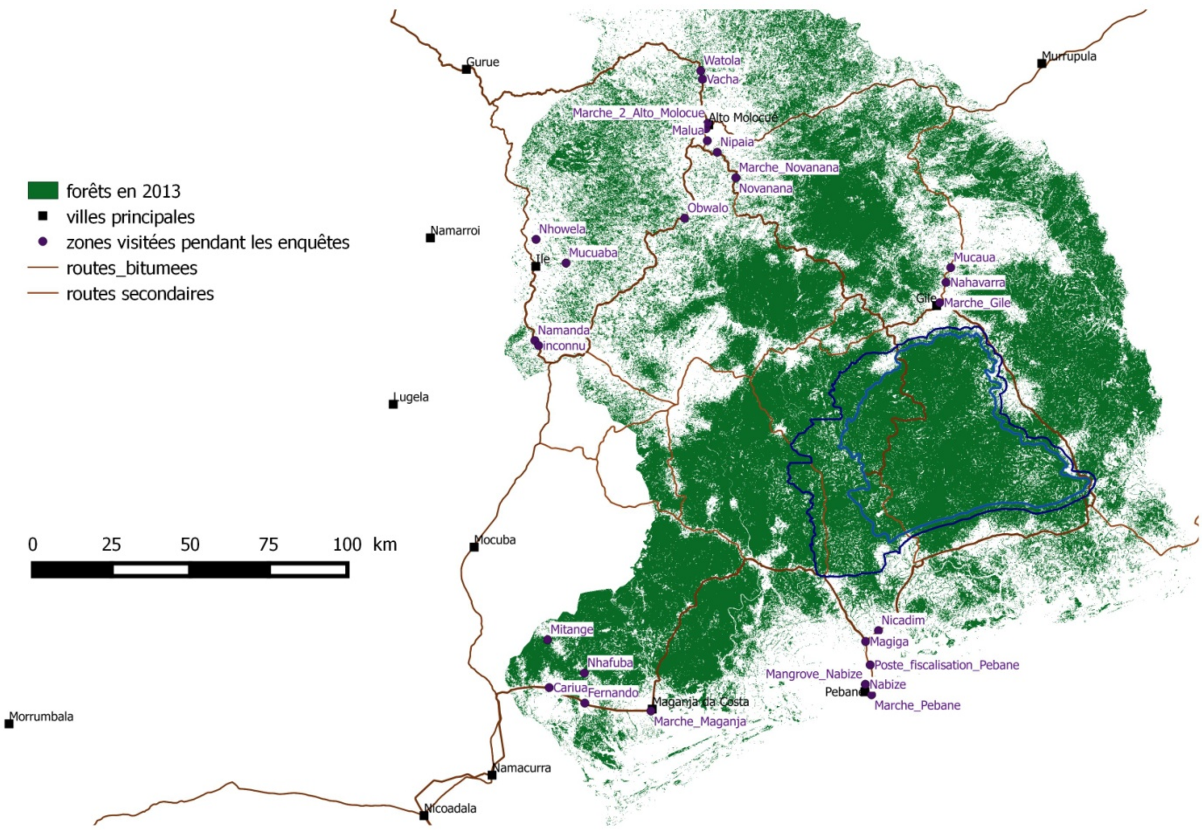


Figure 78: Villages visited in each supply basin during the survey on charcoal value chain, for the part focusing on production

Annex 5: Method for the calculation of emissions due to charcoal production

This calculation is based on estimates on the quantities - in tons - of charcoal produced in the ZILMP program area. In accordance with IPCC recommendations on best practices (see following table for details on calculation), it respects the following features:

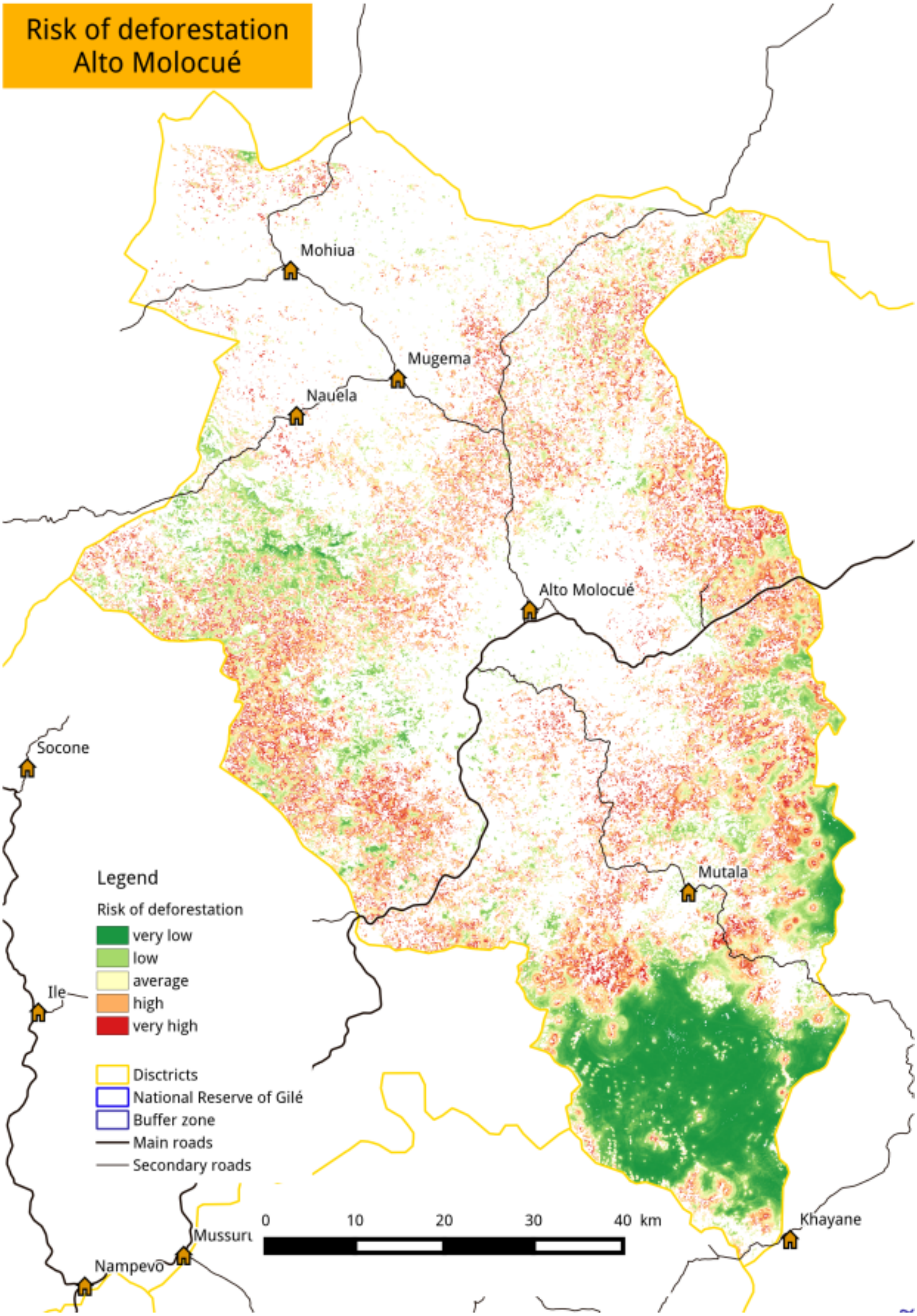
- Calculation on the quantities of charcoal production is considered with regards to the consumption in bags and to the average bag weight, depending on the district (survey results).
- Given this, the quantity of wood that is used by kilns for carbonization is assessed according to a mean kiln yield of 20%.
- On the basis of the total quantity of wood that is used, aboveground biomass is estimated by biomass expansion factors. Default values from IPCC reports were used. Several values can be selected:
  - BEF (Biomass expansion factor) ratio, from the IPCC report (2003) for tropical broadleaf forests: 3.4 tdm/tdm
  - BCEF (Biomass conversion and expansion factor in tdm/m^3), which is related to BEF by wood density (BCEF=BEF.WD), from the IPCC report (2006) for woodfuel removal on hardwoods tropical dry forests: 0.89/0.73=1.22 tdm/tdm
- Given the aboveground biomass, belowground biomass is estimated with IPCC default root to shoot ratio of 0.28 for tropical dry forests (with aboveground biomass above 20 tC/ha).
- Finally, carbon fraction in biomass is considered to be 0.47 tC.tdm^{-1} according to IPCC. A factor of 3.67 is used to convert tons of carbon in tons equivalent CO_2.

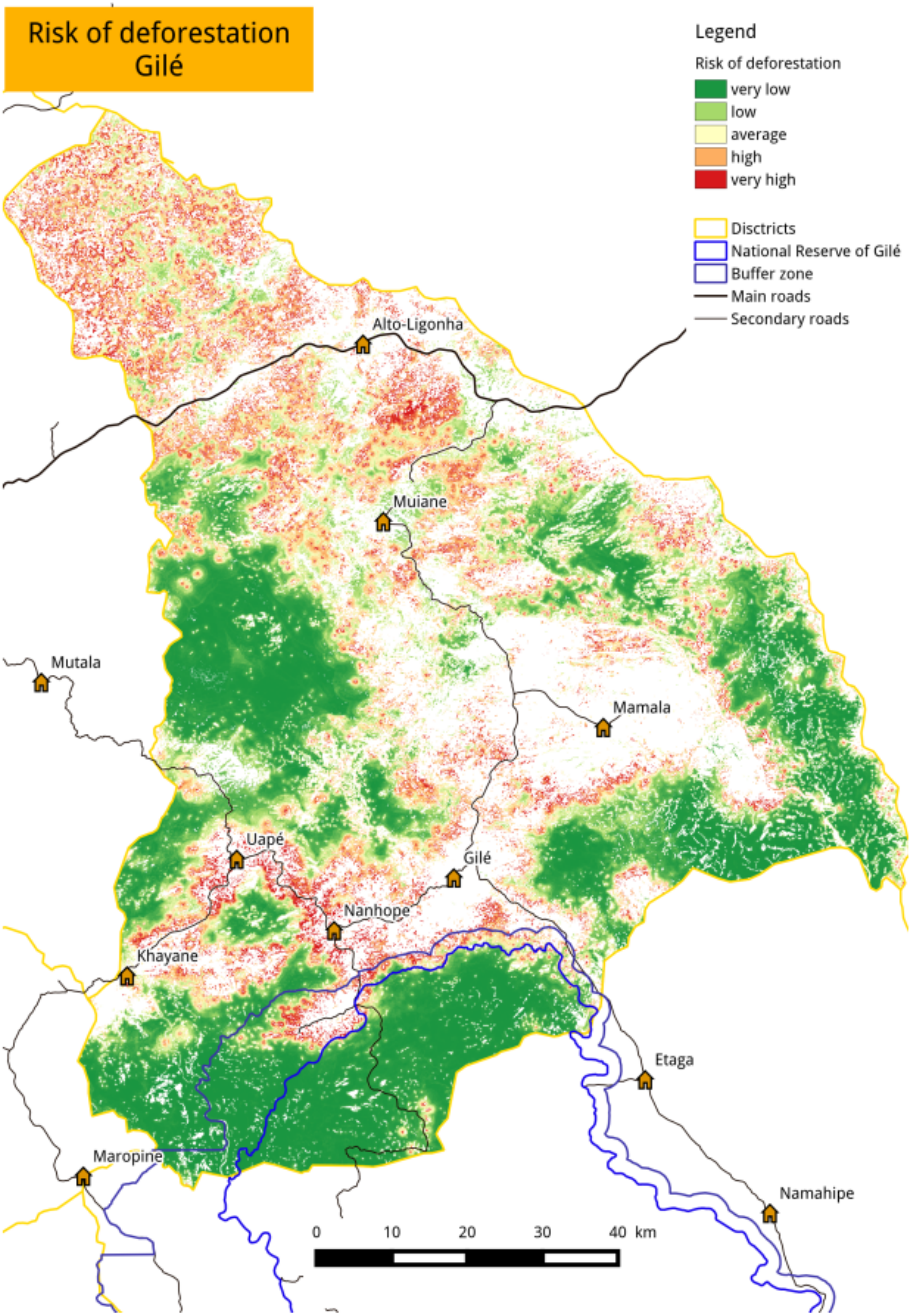
Local value of those estimations (yields, BEF ratio and root-to-shoot ratio) should be used to account for degradation from charcoal into the program REL. Moreover, other than CO_2 GES gas could be taken into account, since they probably have a significant role in the carbonization phase.

Table 52: Summary of the calculation of the emissions due to degradation caused by charcoal production (outside of agricultural fields), based on data from the survey and on several hypothesis for default factors

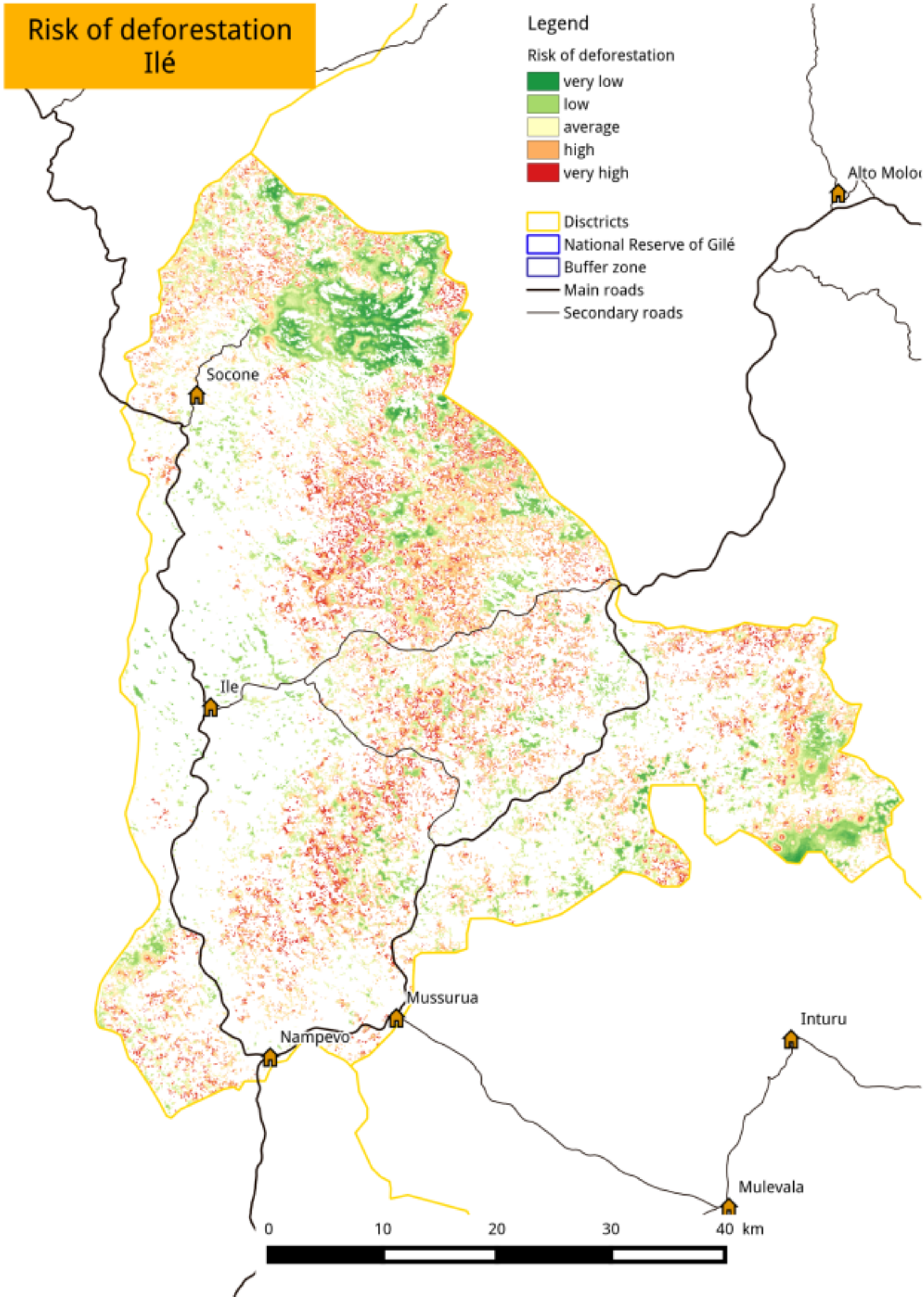
	Produced charcoal in t/yr	**Equivalent of wood used for the kiln in t/yr**	**Equivalent of aboveground tree biomass cut in t/yr**	**Equivalent of total tree biomass in t/yr**	**Equivalent in tC/yr**	**Emissions in tCO_2eq/yr**
Factor used	**Results from survey**	**Kiln yield: 20%**	**BEF: 3.4 tdm/tdm**	**Root-to-shoot ratio: 0.28**	**Carbon proportion: 0.47**	**Molecular ratio: 3.67**
Gilé	3,707	18,537	63,027	80,674	37,917	139,155
Maganja	3,036	15,178	51,606	66,056	31,046	113,940
Alto Molocué	7,634	38,169	129,773	166,110	78,072	286,523
Ilé	3,363	16,816	57,173	73,182	34,396	126,232
Pebane - Miombo forest	2,026	10,131	34,444	44,089	20,722	76,049
Pebane - mangrove	1,658	8,289	28,182	36,073	16,954	62,222
Total	**21,424**	**107,119**	**364,206**	**466,184**	**219,106**	**804,120**
Factor used	**Results from survey**	**Kiln yield: 20%**	**BCEF/WD: 0.89/0.73=1.22 tdm/tdm**	**Root-to-shoot ratio: 0.28**	**Carbon proportion: 0.47**	**Molecular ratio: 3.67**
Gilé	3,707	18,537	22,615	28,948	13,605	49,932
Maganja	3,036	15,178	18,518	23,702	11,140	40,884
Alto Molocué	7,634	38,169	46,566	59,604	28,014	102,811
Ilé	3,363	16,816	20,515	26,259	12,342	45,295
Pebane - Miombo forest	2,026	10,131	12,359	15,820	7,435	27,288
Pebane - mangrove	1,658	8,289	10,112	12,944	6,084	22,327
Total	**21,424**	**107,119**	**130,686**	**167,278**	**78,620**	**288,537**

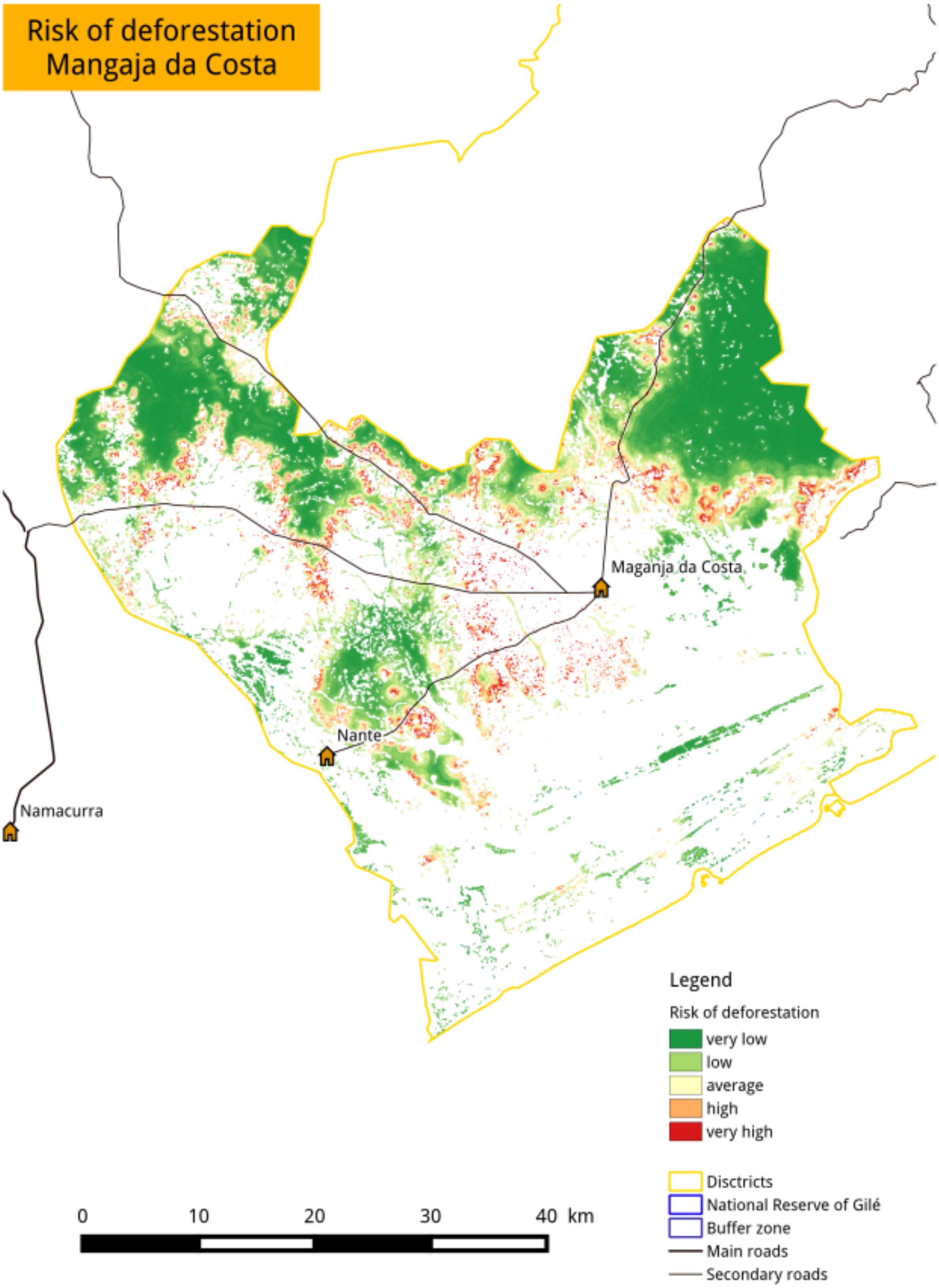
Annex 6: Risk of deforestation maps per district

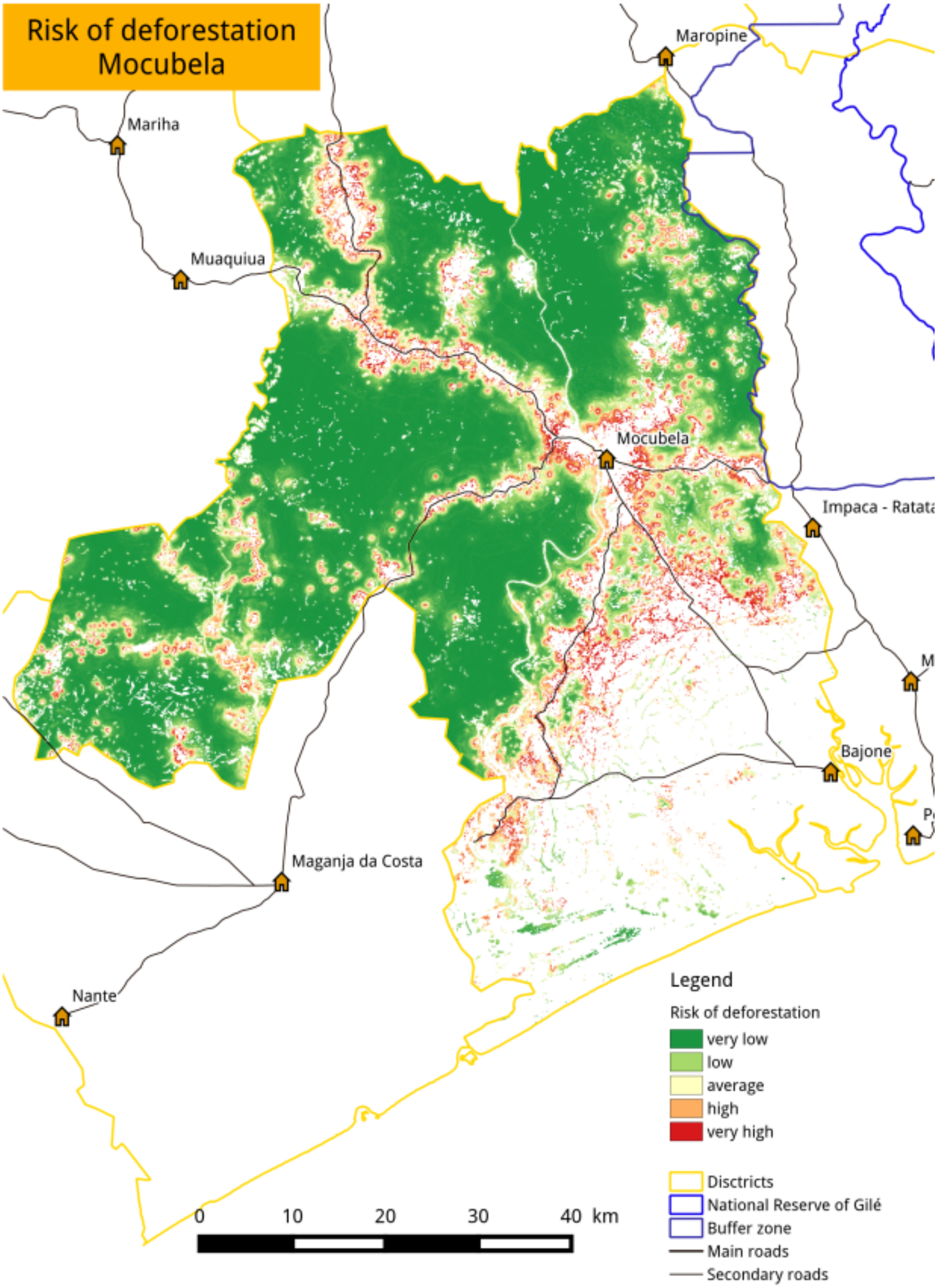


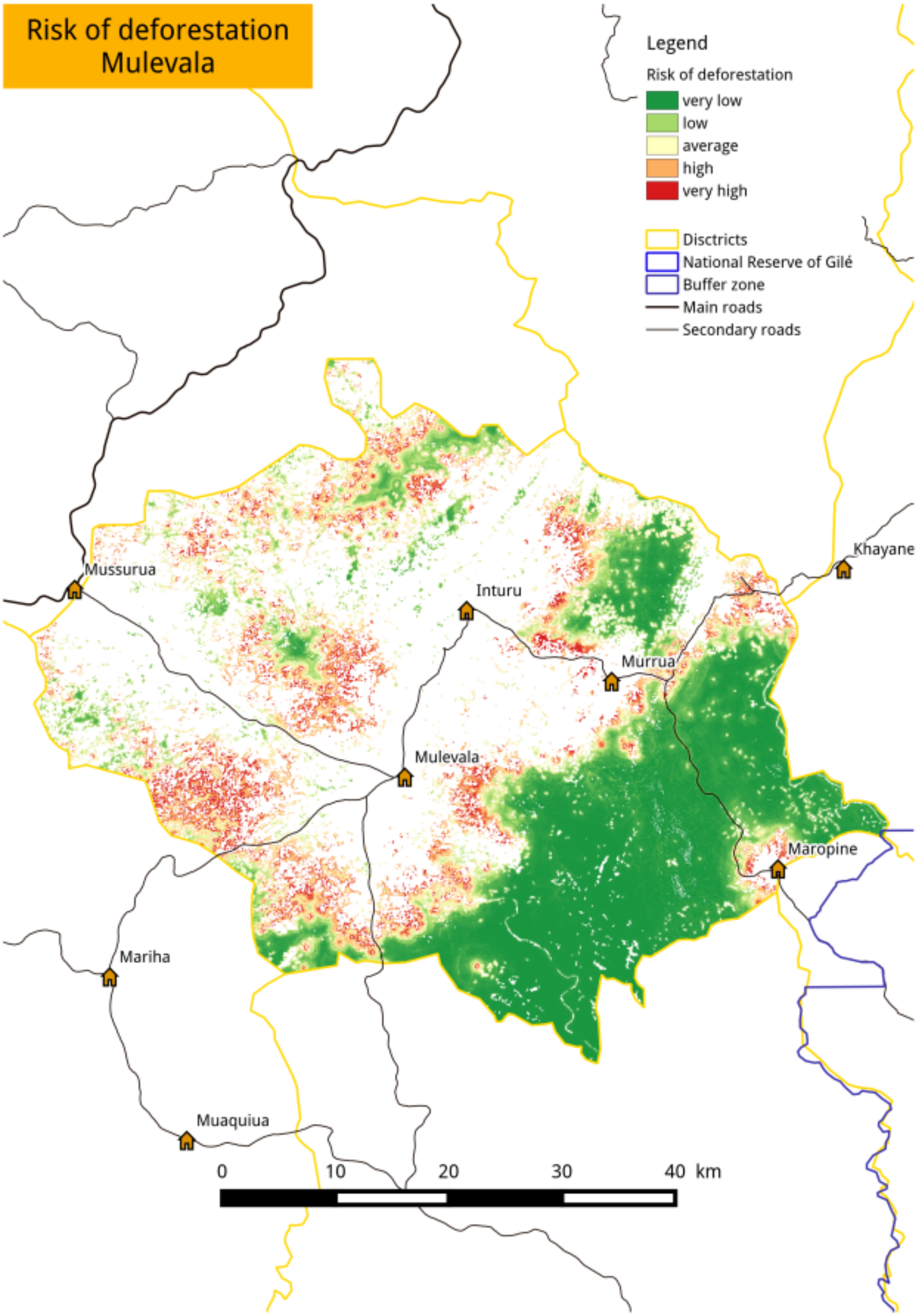


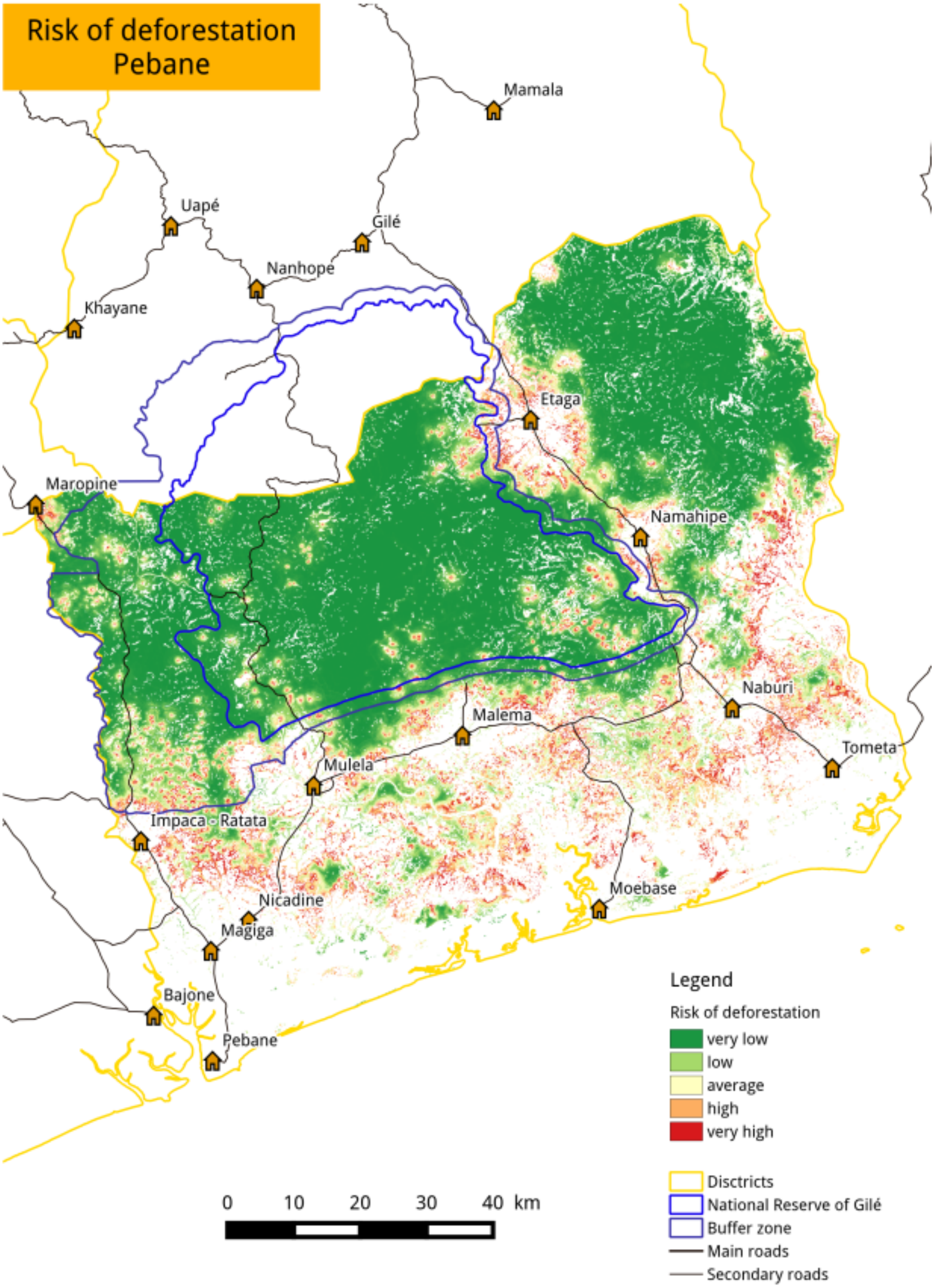
Risk of deforestation Gilé
Legend
Risk of deforestation
very low
low
average
high
very high
Disctricts
National Reserve of Gilé
Buffer zone
Main roads
Secondary roads
Alto-Ligonha
Muiane
Mutala
Mamala
Uapé
Gilé
Nanhope
Khayane
Etaga
Maropine
Namahipe
0
10
20
30
40 km


Risk of deforestation
Ilé
Legend
Risk of deforestation
very low
low
average
high
very high
Disctricts
National Reserve of Gilé
Buffer zone
Main roads
Secondary roads
Socone
Ile
Mussurua
Nampevo
Inturu
Mulevala
Alto Moloc
0
10
20
30
40 km


Risk of deforestation
Mangaja da Costa
Maganja da Costa
Nante
Namacurra
Legend
Risk of deforestation
very low
low
average
high
very high
Disctricts
National Reserve of Gilé
Buffer zone
Main roads
Secondary roads
0
10
20
30
40 km


Risk of deforestation
Mocubela
Maropine
Mariha
Muaquiua
Mocubela
Impaca - Ratata
Bajone
Maganja da Costa
Nante
0
10
20
30
40 km
Legend
Risk of deforestation
very low
low
average
high
very high
Disctricts
National Reserve of Gilé
Buffer zone
Main roads
Secondary roads


Risk of deforestation
Mulevala
Legend
Risk of deforestation
very low
low
average
high
very high
Disctricts
National Reserve of Gilé
Buffer zone
Main roads
Secondary roads
Mussurua
Inturu
Khayane
Murrua
Mulevala
Maropine
Mariha
Muaquiua
0
10
20
30
40 km


Risk of deforestation
Pebane
Mamala
Uapé
Gilé
Nanhope
Khayane
Etaga
Maropine
Namahipe
Naburi
Malema
Tometa
Mulela
Impaca - Ratata
Moebase
Nicadine
Magiga
Bajone
Pebane
0 10 20 30 40 km
Legend
Risk of deforestation
very low
low
average
high
very high
Disctricts
National Reserve of Gilé
Buffer zone
Main roads
Secondary roads

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