Vanuatu's National Forest Reference

[2008 – 2017]

May, 2022

Contributors

Lead:

Ministry of Forestry, Vanuatu

Technical:

Rexon Vira, Willi Lore and their NFI, GIS, administration and logistics teams (Department of Forestry); Dhan Dhital and all REDD+ team members (National REDD+ unit); Brian Phillips (NAB on Climate change); staff from the Agriculture Department and the Department of Lands.

Matthias Seebauer, Alexander Pinkwart, Metodi Panev (Unique land use, Project development NFI, NFMS, FRL); Gabrielle Kissinger (Lexeme Consulting, Drivers of deforestation and degradation analysis and REDD+ Strategy); Carly Green and Felicity Thomas (Environmental Accounting Services, Quality assessment support and UNFCCC FRL Documentation development); Technical support; Eric Bullock (Boston University, CODED degradation detection algorithm); GreenCollar – spatial assessment support.

Acknowledgements

The Government of Vanuatu wishes to express gratitude to the World Bank for the support provided through the ‘REDD Readiness Grant’ which lead to implementation of systems and processes to develop this National Forest Reference Emissions Level (FRL) Report.

Special thanks go to the technical partners Unique Forestry for their collaborative support and technical guidance in developing our National Forest Monitoring System and to EAS for drafting this report.

The Government of Vanuatu is highly grateful for the immense dedication and contribution by all national stakeholders involved in the development of Vanuatu’s National Forest Reference Level.

Contents

List of Tables

List of Figures

List of Acronyms

AD	Activity Data
AGB	Above Ground Biomass
BGB	Below Ground Biomass
CE	Collect Earth
CH_4	Methane
CI	Confidence Interval
CO_2	Carbon Dioxide
COP	Conference of the Parties
DBH	Diameter at Breast Height
DF	Dense forest
DOM	Dead Organic Matter
EF	Emissions Factor
ER-PD	Emissions Reductions Project Document
ESMF	Environmental and Social management Framework
FCPF	Forest Carbon Partnership Fund
FREL	Forest Reference Level
FRL	Forest Reference Level
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
ha	Hectare
IGES	Institute for Global Environment Strategies
IPCC	International Panel for Climate Change
MMU	Minimum Measurement Unit
MOE	Margin of Error
MRV	Measurement, Reporting and Verification
N_2O	Nitrous Oxide
NBSAP	National Biodiversity Strategy and Action Plan
NFI	National Forest Inventory
NFMS	National Forest Monitoring System
NGHGI	National Greenhouse Gas Inventory
NPHC	National Population and Housing Census
OF	Open forest
QA	Quality Assurance
QC	Quality Control
REDD+	Reducing Emissions from Deforestation, Forest Degradation, and the role of Conservation of Forest Carbon Stocks; Sustainable Management of Forests; and Enhancement of Forest Carbon Stocks
R-PIN	Readiness Plan Idea Note
R-PP	Readiness Preparation Proposal
SD	Standard Deviation
SE	Standard Error
SESA	Strategic Environmental and Social Assessment
SOC	Soil Organic Carbon
SPC	South Pacific Community
TCCCA	Transparent, Consistent, Comparable, Complete and Accurate
UNFCCC	United Nations Framework Convention on Climate Change
VCCP	Vanuatu Carbon Credit Project

Key Elements (12/CP.17)

The construction of FREL/FRL as benchmark for assessing performance is guided by modalities contained in UNFCCC Conference of the Parties (COP) decisions, most notably decision 12/CP.17 and its Annex.

Vanuatu has addressed these modalities as outlined below:

- **Paragraph 7.** The FREL/FRL presented by Vanuatu is expressed in tons of CO_2 equivalent per year (t CO_2-e), to serve as a benchmark for assessing the country's performance in implementing the REDD+ activities (section 7).
- **Paragraph 8.** Vanuatu developed a single database for the National GHG Inventory (NGHGI) and the FREL/FRL. This aims to ensure full consistency in future submissions to the UNFCCC (e.g., NGHGI, Biennial Update Report). All calculations are explicit to maximize transparency (section 5)
- **Paragraph 9.** The national circumstances are considered in this FREL/FRL submission (section 1).
- **Paragraph 10.** Vanuatu presents an improvement plan (section 10), which considers how Vanuatu may continuously improve the quality and extensivity of the FREL/FRL in future
- **Paragraph 11.** Vanuatu's FREL/FRL is presented at the national level (section 7).
- **Annex, chapeau.** the information provided by Vanuatu is guided by the 2006 IPCC guidance and guidelines, specifically the 2006 IPCC Guidelines for National GHG Inventories but also the 2019 IPCC Refinement, as appropriate.
- **Annex, paragraphs (a), (b).** A comprehensive database has been established to maintain the data used to develop the estimates in this report. Also, extensive descriptions of the methods and data used are provided (section 5) to facilitate understanding by the readers and the UNFCCC technical assessment team. Supporting reports and reference as also available.
- **Annex, paragraph (c).** Carbon pools included, and reasons for exclusions, are provided. REDD+ activities covered are defined as deforestation, forest degradation and enhancement of carbon stocks (section 2).
- **Annex paragraph (d).** The forest definition used for the FREL/FRL is the same as that applied in the National Forest Policy 2011-2020 (section 2).

National Focal Point

Ms Esline Bule

Director General, REDD+ National Entity & Focal Point

phone: (+678) 2 46 86

Email: gesline@vanuatu.gov.vu

Executive Summary

In accordance with decision 12/CP.17, Vanuatu voluntarily submits its Forest Reference Level (FRL) for consideration by the United Nations Framework Convention on Climate Change (UNFCCC).
This report presents an overview of the methodologies and data adopted to estimate the historical emissions/removals profile as well as details of how these baseline emissions/removals were applied for developing the National FRL.

Vanuatu intends to achieve the following national and international objectives with this submission of a National FRL:

- Continually assess the progress of REDD+ implementation in Vanuatu
- Assess the forest sector contribution to the National Climate Change Mitigation Actions of Vanuatu
- Seek consistency with other National submissions (Nationally Determined Contributions, Biennial Update Report, National Greenhouse Gas Inventory) and future submissions in line with the Paris Agreement
- Contribute to an enabling environment to generate results-based payments for REDD+ Actions taken within Vanuatu
- Contribute to the achievement of the Paris Agreement

Vanuatu's National FRL submission covers the activities "reducing emissions from deforestation", "reducing emissions from forest degradation" and "enhancement of forest carbon stocks (afforestation/reforestation)", which are among the activities included in the UNFCCC decision 1/CP.16, paragraph 70. Vanuatu's FRL is national in scale, covers the Reference Period 2008–2017 and is based on a simple historical average approach. It comprises a detailed set of carbon pools and CO_2 as the only gas accounted for.

This document and accompanying materials offer detailed information on historical emissions from all included REDD+ activities, as well as methods applied and data sources used to derive estimates of emissions and removals. Activity Data and emissions factors were calculated from sample points on a systematic grid across the country with different levels of intensification.

The FRL amounts to average net emissions of 732,441 tonnes of carbon dioxide emissions equivalent (tCO_2e) per year. The FRL comprises deforestation and forest degradation and partially carbon stock enhancement, to the extent that carbon stock enhancement is linked to a transition of non-Forest land use to forest. Carbon stock enhancements in forests remaining forests are not represented in the present FRL.

Deforestation accounts for 577,733 tCO_2e on average per year over the Reference Period. Degradation, monitoring and reported as the transition from Dense forest to Open forest, accounts for 199,502 tCO_2e on average per year. Together, deforestation and degradation represent gross emissions of 777,235 tCO_2e. Carbon stock enhancement, Open forest growing back on prior Cropland, Grassland or other land, removes 44,794 tCO_2e on average per year, slightly less than 5% of gross emissions from deforestation and forest degradation.

This FRL assessment indicates that during the 10-year Reference Period approximately 23,841 ha of forest has been cleared and converted to other land use, which is equivalent to 0.26% forest loss per year during this period. A further 21,638 ha of forest was degraded between 2008 and 2017. While only 2,384 ha of land returned to forest from other land use categories during the Reference Period.

1 Introduction

1.1 Overview of Vanuatu

Vanuatu is located in the South Pacific Ocean, about 1,750 km east of Australia and 500 km north-east of New Caledonia. Vanuatu includes more than 80 islands, of which about 65 are inhabited, which make up a land area of 1.23 million hectares, and a combined coastline of 3,132 km. Vanuatu's island chains are mostly of volcanic origin. The highest peak of Mount Tabwemasana rises to 1,879 m above sea level on the island of Espiritu Santo. The weather is tropical, characterised by moderate rainfall from April to November and cyclones from December to April[1].

Vanuatu's population was estimated to be 319,918 in 2022[2]. While about 75 % of the population is rural, it is predicted that by 2050, this will drop to about 60% as more people move into urban areas[3]. Vanuatu's Human Development Index value for 2018 was 0.597, placing the country in the medium human development category, at 141 out of 189 countries and territories. Vanuatu graduated from the Least Developed Countries status to the Developing Country status in December 2020.

The Vanuatu economy is based largely on agriculture, fishing, tourism and offshore financial services. As most exports are agricultural – for example, copra, coconut oil, kava, beef, timber, cocoa and coffee, Vanuatu is vulnerable to fluctuations in world commodity prices[4]. Many islands are remote and isolated, resulting in high transport costs for agricultural and other products seeking markets in Port Vila and beyond. In addition to the formal economic sector, the informal economy involves at least 84% of the population.

According to the National Forest Inventory of 2021, 75% of land area is covered with both closed and Open forest.[1] Forest types include tropical lowland evergreen rain forest, broad-leaved deciduous forest, closed conifer forest, montane rain forest, cloud forest and coastal forest. Other notable vegetation includes swamp forest on Efate, kauri pine stands on Erromango and scattered mangrove forests covering around 724 ha (most of which occur on Malekula Island).

Lowland forest has largely been cleared and replaced by anthropogenic vegetation but forested areas remain the dominant landscape element on most islands. High forests are restricted in range on most of the islands (especially those that are densely populated, such as Pentecost, Ambae, Tanna and Shepherd; or have active volcanoes, such as Ambrym). However low montane forests are generally well preserved and occupy large areas. Secondary forests (often consisting of a Hibiscus community) are dense and extensive in Vanuatu[1].

[1] The NFI Team defined forests as: Dense Forest: natural forests with canopy cover higher than 40%; Open Forest: natural forests with canopy cover 10-40%; Forest Plantations: Established Forest plantations with active management.

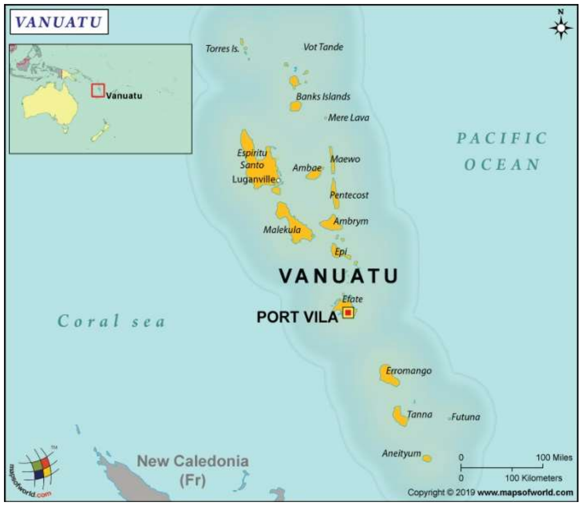


Figure 1:Location of Vanuatu

1.2 Effects of Climate Change in Vanuatu

Vanuatu, like many other island nations in the South Pacific will bear the brunt of the changing climate in the coming years. It is predicted that by 2030, temperatures will increase in Vanuatu by up to 1° Celsius per year. The sea surrounding Vanuatu has already risen 6 millimetres per year since 1993, and will continue to rise. Additionally, extreme rainfall events will grow in frequency and intensity, increasing the resulting damages spurred by cyclones, storm surges, landslides, flooding and droughts[5].

Cyclones are likely to be less frequent, but more severe, endangering the country's economy and the population's livelihood[2]. Root crops, such as sweet potatoes and plantains provide food and income for the majority of Vanuatu's rural population. However, changing rainfall patterns cause damage to seedlings and soil and cause contamination of the environment in which crops grow increasing the threat of pests and diseases which will have subsequent negative impacts on food security.

Rising ocean temperatures will also have a significant impact on marine fisheries by changing habitat temperatures which will significantly influence their metabolism, growth, reproduction and distribution. Other impacts that Vanuatu is and will continue to experience include coastal erosion and ocean acidification. These developments are not only a risk to food security but also other industries such as tourism with the loss of coral reefs and fragile ecosystems.

1.3 Overview of Land Ownership in Vanuatu

Honouring customary land tenure is an important constitutional right in Vanuatu. At independence in 1980, the new Constitution restored perpetual land rights to the "indigenous custom owners and their descendants" and proclaimed that the "rules of custom shall form the basis of ownership and use" in the country[6].

[2] Cyclone Pam, which hit Vanuatu in 2015, destroyed 96 percent of the island's food crops.

Over the last twenty years, Vanuatu has experienced a dramatic land rush with over 10% of all customary land now leased[7]. On Efate Island, which hosts the capital city of Port Vila, 43.6% of land previously held under customary tenure is now leased. Beyond Efate Island, Santo Island accounts for most of the leased land with over 10% of the land mass held under lease. Agricultural leases account for 82% of leased land across the country. This is particularly significant for islands that are beginning to face a critical land shortage, such as Efate Island. Much of the land held under existing Agricultural leases is environmentally degraded due to overgrazing or the planting of long-term coconut plantations.

Ninety percent of customary land is unleased, which means landowners have unalienable rights to use their land according to their own terms. Land is closely linked with cultural and clan heritage, power structures, and spirituality. Most ni-Vanuatu have access to land through customary systems. Rights to land often depend upon oral histories, 'memory culture', complex local categories, and varying inheritance practices.

Most of the high value forests were over-exploited in the 1980s and 1990s, until the government imposed a ban on the export of round logs in 1998. Large areas of logged-over forests and abandoned agricultural land have been invaded by the introduced invasive vine Merremia peltate (Big Lif), which impedes the natural regeneration of the logged forest. Many landowners have used their logged Forest lands for alternative activities such as commercial agriculture[1].

1.4 Overview of Drivers of Land Use Change

Direct drivers of deforestation or forest degradation are human activities that directly impact forests and land[8], such as logging, agricultural expansion, or infrastructure and road development. These are observable, but the underlying causes that motivate the drivers are hard to detect.

The analysis of Activity Data using a sample-based approach to conduct analysis of remote sensing imagery covering different islands, formed the basis of assessment of the land cover and land cover change for the Reference Period from 2008 to 2018. Open Foris Collect Earth was used to assess the available imagery in the archive. The Activity Data analysis represents the assessment of land cover and land cover change and reflects the most recent drivers and underlying causes influencing the forest resources of Vanuatu.

1.4.1 Deforestation

Analysis of land use change between 2008 and 2017 (Table 1) indicates that forestland was lost as areas of Cropland, Grassland and settlement experienced high rates of expansion. Cropland is the land use category with the highest growth in area of 15,689 ha over the 10-year Reference Period. Settlements followed by Grasslands were other notable increases. Thus, conversion to Cropland accounted for 70% of forest loss, while conversion to Grasslands accounted for 11% and conversion to settlement accounted for 9% of forest loss between 2008-2017 (See Figure 2).

Table 1: Land use change (2008 – 2017)

Land use type	Area 2008 (ha)	Area 2017 (ha)	Area change (ha)	Rate of change
Cropland	141,123	156,812	15,689	11.1%
Forest	947,970	926,513	-21,457	-2.3%
Grassland	39,622	41,197	1,575	4.0%
Other Land	75,733	76,491	758	1.0%
Settlements	14,510	17,930	3,420	23.6%
Water Body	3,706	3,720	14	0.4%
Wetlands	1,003	1,003	-	0.0%
Total	1,223,667	1,223,667	0	0.0%

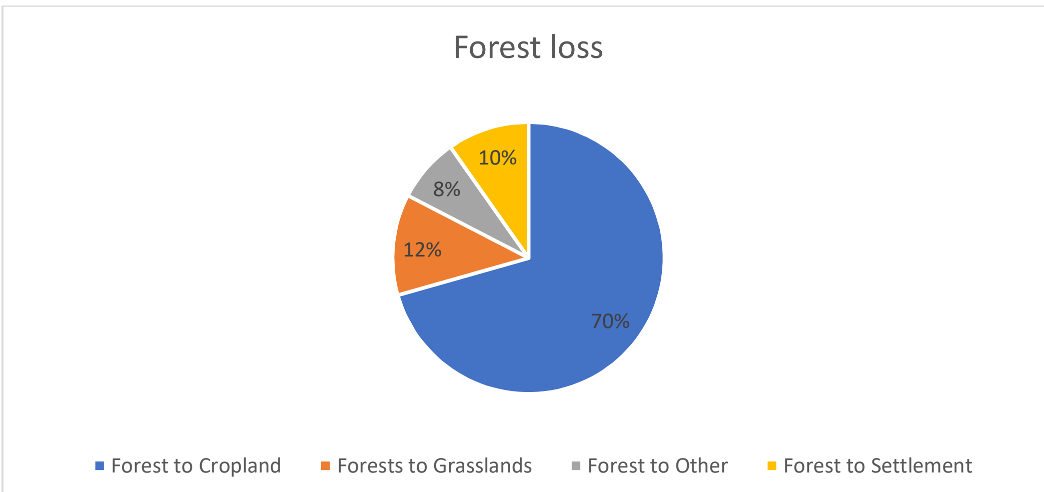


Figure 2: Forest loss by type (2008 - 2017)

An overall pattern of slightly increasing forest loss each year is visible, showing a general trend of increasing forest loss to Cropland each year (Figure 3). The rate of forest loss was 0.26% per year between 2008 – 2017.

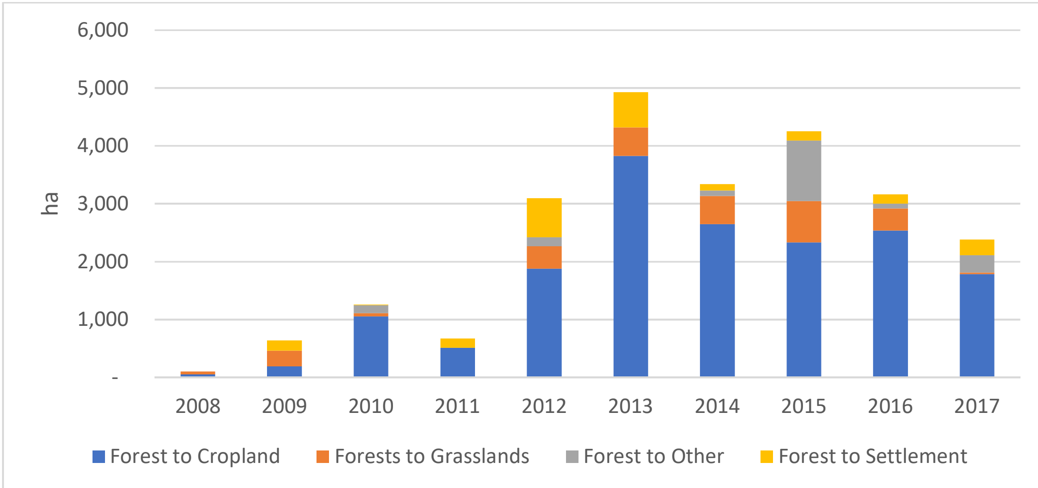


Figure 3: Activities causing forest loss (2008 – 2017)

1.4.2 Forest Degradation

Forest degradation is either human induced or from natural occurrences. The sample-based approach, based on satellite imagery, illustrates that 68% of forest degradation in Vanuatu occurred due to human-induced changes to the forest. Whereas 32% of degradation is attributed to natural occurrences, predominately cyclones. What is clearly apparent in the data on forest degradation is the effect of Cyclone Pam on Vanuatu's forests in 2015, which is visible in Figure 4.

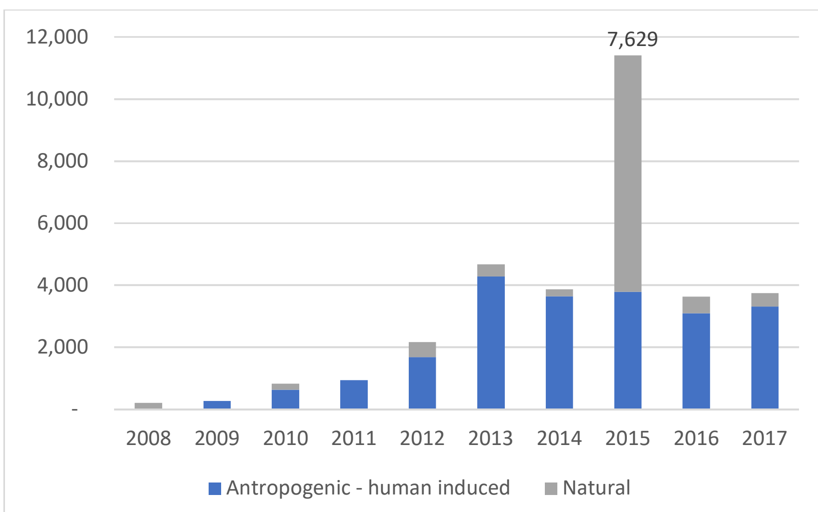


Figure 4: Forest degradation (2008 – 2017)

The trend indicates a general increase over the 10-year Reference Period in forest degradation attributed to human activity. Attributing forest degradation to specific activities highlights the large impact of agriculture on Vanuatu's forests. Agriculture contributed 51% of observed degradation between 2008-2017 (See Figure 5). That was followed by cyclone impacts, contributing 22% of forest degradation over the Reference Period.

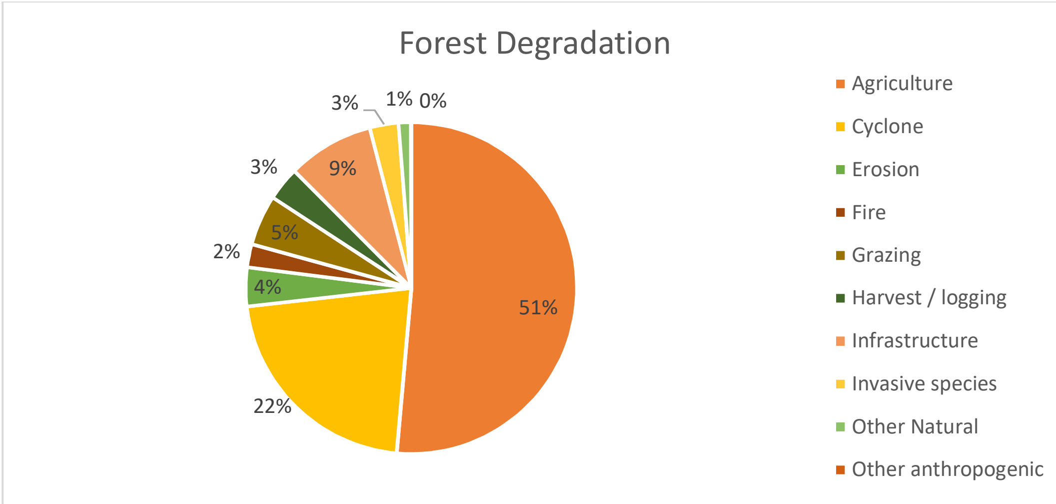


Figure 5: Activities causing forest degradation (2008 – 2017)

Other activities such as erosion, fire, cattle grazing, timber harvesting, infrastructure and invasive species contribute between 3-9% each. It should be noted that this analysis may underestimate Merremia peltata and other invasive species that would appear as canopy cover in the visual assessment of satellite images and is a limitation of the analysis of remotely sensed images.

1.5 Consideration of Sub-National Trends in Deforestation and Forest Degradation

Ranking islands according to anthropogenic impacts on forests allows action to be prioritised in regions of have high human disturbance. These would be 'hot spot' islands, where it is anticipated that based on previous population and human land-use dynamics, these islands will have high potential for similar patterns in the future. Another indication for future risk of forest loss is the ratio of Dense vs Open forest, presented in Table 2. Open forest is more often affected by humans, such as through agriculture, fallows, Grasslands, etc. This ratio therefore provides a way of analysing the relative influence of drivers of deforestation on individual islands,[3] where a high ratio represents an island with a lower anthropogenic risk of deforestation and degradation, whilst a low ratio represents a higher risk. When considering anthropogenic influences on the forest, Efate, Epi, Maewo, Erromango, and Pentecost are the islands most affected by anthropogenic influence.

[3] Islands with high volcanic activity should be considered separately as they contain large amounts of bare land, due to volcanic eruptions or ashfall (Ambae, Ambrym, Tanna). Erromango also has a high amount of bare land.

Table 2: Anthropogenic risk ratio

Island	Ratio: Dense forest/ Open forest
Efate	1.7
Epi	2.1
Maewo	2.3
Erromango	2.4
Pentecost	2.6
Malekula	3.8
Gaua	6.4
Espiritu Santo	8.0
Ambae	8.1
Tanna	11.1
Ambrym	11.5
Aneityum	13.5
Vanua Lava	35.7

1.6 Vanuatu's National REDD+ Program and Readiness Progress

The REDD+ readiness process in Vanuatu began in 2007 with the establishment of Vanuatu Carbon Credits Project (VCCP). This was followed by the South Pacific Community (SPC) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) regional project, 'Climate Protection through Forest Conservation in Pacific Island Countries,' funded by the International Climate Initiative of the German Federal Environment Ministry. Efforts by Live and Learn International and the Nakau Programme, an independent Pacific regional forest protection and enhancement financing programme, were also under way at the same time which resulted in the Nakau Programme's Loru Forest Project on Santo, as a performance-based forest carbon offset project[10]. The Loru project generates 2,442 carbon offsets annually, and is certified under the Plan Vivo standard.

With the support of SPC/GIZ, Vanuatu has become a participant country of the World Bank's Forest Carbon Partnership Facility (FCPF). Vanuatu submitted its first Readiness Plan Idea Note (R-PIN) in July 2008. The R-PIN provided an initial overview of Vanuatu's land use pattern and the causes of deforestation as well as stakeholder consultation process and institutional arrangements for REDD+ readiness. The Government of Vanuatu established a REDD+ Technical Committee and formulated a Readiness Preparation Proposal (R-PP).

Vanuatu's 2013 Readiness Proposal (R-PP) identified the country's interest to implement a national approach for REDD+, which would invest in sustainable land use activities and thereby lower the rate of deforestation and forest degradation, and associated GHG emissions[11] . The R-PP identified that the main benefit for the ni-Vanuatu will be the enhancement of sustainable economic activities and increase of incomes with national investment programs. This goal remains today, although the finance source, modalities, and institutional arrangements envisaged have shifted.

In April 2015, the World Bank Forest Carbon Partnership Facility (FCPF) Participants Committee approved a grant of US$ 3.6 million to enhance readiness of Vanuatu for REDD+ implementation. The grant was designed to:

i) strengthen the institutions for REDD+ at the national and sub-national level through the Vanuatu REDD+ Unit, support to Technical Committee, National Advisory Board on Climate Change and Disaster Risk Reduction and its Project Management Unit and set up of Provincial REDD+ Committees;

ii) strengthen decentralized structures for stakeholder engagement, including the assessment and improvement of existing feedback grievance redress mechanisms for REDD+; and

iii) development of national REDD+ strategy, carry out a Strategic Environmental and Social Assessment (SESA) and prepare an Environmental and Social management Framework (ESMF).

Additional financing was granted in 2018 to support the estimation of emission factor data based on a national forest inventory of selected islands, the assessment of Activity Data on forest cover and forest cover change based on remote sensing, development of a National Forest Reference Level (FRL) and Development of MRV (Measuring, Reporting and Verification).

2 Definitions

2.1 National Forest Definition

According to the National Forest Policy 2011-2020 and for REDD+ reporting purposes the following forest definition applies in Vanuatu:

"Land spanning more than 0.5 hectares[4] with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ."

The operational forest definition slightly differs from the national forest definition insofar as a minimum mapping unit (MMU) of 0.81 ha was applied.

2.2 Classification of Forest Types

Land cover is represented by nine nationally defined land cover classes corresponding to each of the six broader IPCC land cover classes. The land cover class Forest land is represented in detail by four nationally defined land cover classes (dense and Open forest, forest plantations and mangroves). Table 3 lists the national land cover classes and definitions compared to the IPCC categories. More details on the National Forest Monitoring System (NFMS) can be found in Section 5.

[4] The operational forest definition slightly differs from the national forest definition insofar as a minimum mapping unit (MMU) of 0.81 ha was applied.

Table 3: Definition of IPCC Land-Use categories and national subdivisions adopted by Vanuatu.

IPCC land cover classes	VANRIS land cover types	Description
Forest	Dense forest	Natural forests with canopy cover higher than 40%
	Open forest	Natural forests with canopy cover 10-40%
	Forest Plantations	Established forest plantations with active management
	Mangroves	Natural forests dominated by mangrove species
Cropland	Cultivated lands; annual crops and fallow	Crops that are planted annually, including gardens
	Cultivated lands; perennial crops; coconut plantations	Perennial crops, including agroforestry systems
Grassland	Grassland	Grassland includes natural Grasslands and livestock pastures
Settlements	Settlements	Settlements and infrastructure
Waterbody	Waterbody	
Other	Shrubs Bare soil No data	

2.3 REDD+ Activities

The Vanuatu FRL encompasses three of the five REDD+ activities defined in UNFCC decisions:

- reducing emissions from deforestation
- reducing emissions from forest degradation
- enhancement of forest-carbon stocks (afforestation of land not previously forest, reforestation of land previously converted from forest to another land use)

Due to lack of data, the FRL does not comprise of REDD+ activities relating to the conservation of forest-carbon stocks, enhancement of forest-carbon stocks (Forest land remaining Forest land) and sustainable management of forests. Vanuatu aims to include these activities as part of the improvement plan, following the implementation of a second cycle of the National Forest Inventory (NFI). This is part of Vanuatu's effort to improve the quality of its FRL over time. This proposed approach is in line with UNFCCC decisions enabling countries to undertake gradual improvement over time of their data and methods (paragraph 10, of decision 12/CP.17).

Subsections 2.3.1 to 2.3.3 detail emissions sources and Table 4 provides an overview of REDD+ activities included in this FRL with their subsequent loss and gain categories. For all activities it is assumed that the carbon stocks from all pools were committed to the atmosphere immediately at the time of disturbance.

Table 4: Organization of the emissions reporting by REDD+ activity. Green shaded rows are included in the Vanuatu's FRL, grey rows are not.

REDD+ Activity	Losses	Gains
Deforestation	Forest land to non-Forest land-Use: • Dense forest (DF) to Cropland • Open forest (OF) to Cropland • DF to Grassland • OF to Grassland • DF to Settlement • OF to Settlement • DF to Other land • OF to Other land	None
Forest degradation	Forest land remaining Forest land: • Degradation of DF to OF	None
Carbon stock enhancement	None	Non-Forest land-Use Categories to Forest land: • Agricultural land to Open forest • Grassland to Open forest • Other land to Open forest

2.3.1 Deforestation

The REDD+ activity "Deforestation" comprises of carbon biomass losses due to forest cover losses where a change in land-use has been observed to be permanent until the end of the Reference Period (Forest land to non-Forest land-use categories). Whereas the land cover assessment presented in Table 3 distinguishes four forest classes, only the two types of natural forests, namely Dense forests and Open forests were subject to measurable forest conversion[5].

By definition, only anthropogenic factors of deforestation are considered in greenhouse gas reporting. This includes expansion of Cropland, Grasslands, Settlements, and other land. Natural causes of deforestation such as barren lava streams following volcanic eruptions and windthrows as a result of cyclones or strong winds have been tracked by Vanuatu's National Forest Monitoring System (NFMS) but are not considered here even though the play a significant role in deforestation in Vanuatu.

Where a change in land-use has been observed for at least 5 years it is considered by Vanuatu to be permanent and is therefore this loss of carbon biomass is considered deforestation. The permanent nature of forest loss has been tracked using Vanuatu's NFMS.

The REDD+ activity "Deforestation" comprises of carbon biomass losses due to forest cover losses where a change in land-use has been observed to be permanent until the end of the Reference Period

[5] Areas of mangroves and Forest Plantations are of such small scale in Vanuatu they were not detected in the sample based approach applied.

(Forest land to non-Forest land-use categories). A permanent loss of forest cover is considered where a change in land-use has been observed for at least 5 years.

2.3.2 Forest degradation

Biomass losses in Forest land remaining Forest land are characterized as the reduction in biomass in these forests and can be described as forest degradation. Forest degradation in the case of Vanuatu is accounted for as a shift from Dense forests to Open forests. Drivers of forest degradation include shifting cultivation, grazing under the canopy, logging, and minor infrastructure expansion. Again, natural causes of forest degradation such as cyclone or wind damages, fire, and presence of invasive species have been omitted from the present calculation.

2.3.3 Carbon stock enhancement

Carbon stock enhancement occurs as a transition of Non-Forest land-use categories to Forest land. Three transitions have been recorded by the NFMS and are accounted for: i) transition of Cropland land, ii) Grassland or iii) Other land to Open forest. Other transitions such as the grow back of Open forest to Dense forest might occur but have not been recorded by the NFMS during the Reference Period.

Although significant, carbon stock enhancement in Forest land remaining Forest land has not been accounted for in this present communication owing to the lack of data. The repetition of the NFI in due time will allow these gradual changes to be tracked. Carbon stock enhancement in Forest land remaining Forest land is intended to be included as part of the improvement plan.

3 Scope

3.1 Geographic

The accounting area of the FRL is the land area within the political borders recognized by Vanuatu and amounts to 1,289,000 ha. REDD+ is addressed at the national level by Vanuatu. Vanuatu is an archipelago consisting of a total of 83 mostly small islands. The collection of Activity Data and emission factors (EF) covered 13 major islands covering 89% of the total land area of Vanuatu and all of the forested area of Vanuatu. The remaining 11% of land area is primarily Volcanic atolls with no forest cove and is therefore not relevant to the FRL.

3.2 Reference Period

A 10-year historical period spanning from (and including) 2008 to 2017 has been adopted as Vanuatu's Reference Period. Vanuatu chooses not to follow the 20-year Reference Period suggested by the IPCC[12] due to fast biomass recovery in tropical conditions. The selected Reference Period reflects Vanuatu's efforts to reduce emissions from deforestation and forest degradation, including after the 2014/2015 when cyclone Pam devastated larges areas of Vanuatu. While direct impacts of the cyclone on forests such as large-scale windthrows are excluded from the calculation, its indirect, anthropogenic effects are significant and as such are included in the present FRL. The same 10-year Reference Period is applied to all REDD+ activities, deforestation, forest degradation and carbon stock enhancement.

3.3 REDD+ Activities

The FRL encompasses three of the five REDD+ activities:

- reducing emissions from deforestation;
- reducing emissions from forest degradation;
- enhancement of forest-carbon stocks (land converted to Forest land).

Due to lack of data, the FRL does not comprise of REDD+ activities relating to the conservation of forest-carbon stocks, enhancement of forest-carbon stocks (Forest land remaining Forest land) and sustainable management of forests. Vanuatu aims to include these activities as part of the improvement plan, following the implementation of a second cycle of the National Forest Inventory (NFI).

3.4 Carbon Pools

Above-ground live biomass (AGB), below-ground live biomass (BGB) and dead organic matter (DOM) comprising both standing and lying deadwood, as well as stumps and litter, are included in the FRL. Carbon stock changes for soil organic carbon (SOC) are not included in the transition of Forest land converted to non-Forest land-Use due to lack of data. Therefore, it is recommended that Vanuatu includes SOC as part of the improvement plan, following the collection of country-specific data on soil carbon stock changes due to land-use and management changes.

3.5 Greenhouse Gases (GHG)

Only carbon dioxide (CO_2) is included in Vanuatu's FRL. Vanuatu acknowledges that N_2O and CH_4, from wildfires and the burning of agricultural residues might be a relevant source of emissions and aims to include it as part of the improvement plan, following the collection of country-specific data.

4 Compliance with IPCC Guidance and National Forest Monitoring

4.1 Good Practice

Paragraph (b) of the Annex of decision 12/CP.17 (Guidelines and procedures for the technical assessment of submissions from parties on proposed forest reference emission levels and/or forest reference levels; UNFCCC, 2012) states that the information provided by countries during the FRL/FREL submission should be transparent, complete, consistent, and accurate. Vanuatu has followed these guidelines as outlined below:

- **Transparency:** Vanuatu's FRL is openly available online at the UNFCCC information hub. The document is accompanied by an Excel workbook, a user-guide and a folder of supplementary information containing all the raw data, publications and reports used to construct the FRL. Due to its complexity, it was not possible to present all calculations and data points in the written document to allow independent reconstruction of the FRL. Therefore, it is necessary to consult the accompanying FRL workbook in order to fully understand the FRL document. To facilitate cross-referencing of data and calculations, Tables and Figures in the workbook are referenced throughout the written document.
- **Completeness:** This principle refers to the coverage of all relevant sinks, sources, gases and the full geographic coverage of the terrestrial surface of Vanuatu. Where potentially relevant elements for the FRL calculation have been omitted, this is flagged accordingly in the respective section.
- **Consistency:** The methodologies and data used are consistent with the guidance provided by the IPCC. The net removals are estimated in a way that is consistent and will remain functionally consistent as Vanuatu implements its various national policies and measures. The FRL is established maintaining consistency with anthropogenic forest-related greenhouse gas emissions by sources and removals.
- **Accuracy:** Estimates of emissions and removals are accurate as fair as practicable and are supported by QA/QC processes and procedures embed throughout the NFMS. Estimates of uncertainty are represented at the 90% confidence interval.

4.2 Tiers and Approaches

The IPCC has released extensive Guidance and Guidelines[12],[13] regarding the estimation of emissions and removals from Forest land, which Vanuatu has considered for the development of its FRL. The IPCC recommends the use of higher tier methods (i.e., Tier 2 or 3) which are generally considered to be more accurate than lower tier methods on condition that adequate data are available to develop, evaluate and apply a higher tier method[13].

The present FRL is predominantly composed of information at Tier 2 which has been developed from nationally generated Activity Data and Emissions Factors. Activity Data is estimated using a sample-based analysis. Similar analyses have been conducted in the South Pacific and other regions[14] with overall good results and accuracies. The sample-based approach proposed by Olofsson et al. (2014) uses a set of sample plots which were distributed across the country of Vanuatu. For these sample plots a set of attributes were assessed using high resolution imagery from Google Earth. This allowed a statistical estimation of the land cover and all disturbances detected during the Reference Period (see Section 8 on uncertainty analysis for details). In terms of Emissions Factors, national datasets include carbon stock data from Vanuatu's National Forest Inventory which took place from 2019 until 2021 and consists of a series of 832 permanent sample points (clusters, with 4 sample plots per cluster, upland and mangrove clusters mixed). The NFI 2019 was the first performed since 1993 and presents a significant improvement in terms of accuracy and precision compared to previous datasets. The analysis of the NFI data for emissions reporting allowed the calculation of carbon stocks according to various land-use categories and the generation of emission factors for land use transitions.

However, the time elapsed between the two NFI from 1993 until 2019 was too long to allow for a re-analysis and calculation of changes of biomass stocks over time. Therefore, it was not possible to calculate carbon stock enhancements in the land use class Forest remaining Forest.

4.3 Consistency with National GHG Inventory

In 2020 Vanuatu submitted its 3rd National Communication based on the 3rd National GHG Inventory [15]. The present FRL is not fully consistent with the 3rd National Communication, where the Republic of Vanuatu is depicted as net carbon negative, since the land-use change and forestry sector is a net sink of CO_2 in Vanuatu. In the 3rd National Communication, the CO_2-eq removals from the forestry sector were estimated 6.973 Mt of CO_2e for the year 2015. The communication comprised only an assumed steady sequestration rate of forests remaining forests and it did not consider any deforestation or forest degradation.

Future consistency in reporting of emissions and removals from the AFOLU sector is planned between REDD+ reporting the National Communications. Consistency in Activity Data and Emissions Factors as well as scope of included change and stable land classes is planned.

5 National Forest Monitoring System

An operational National Forest Monitoring System has been designed and developed during 2019 and 2021, which is currently (as of February 2022) in its final stages of design and approval. The system design is illustrated in Figure 6.

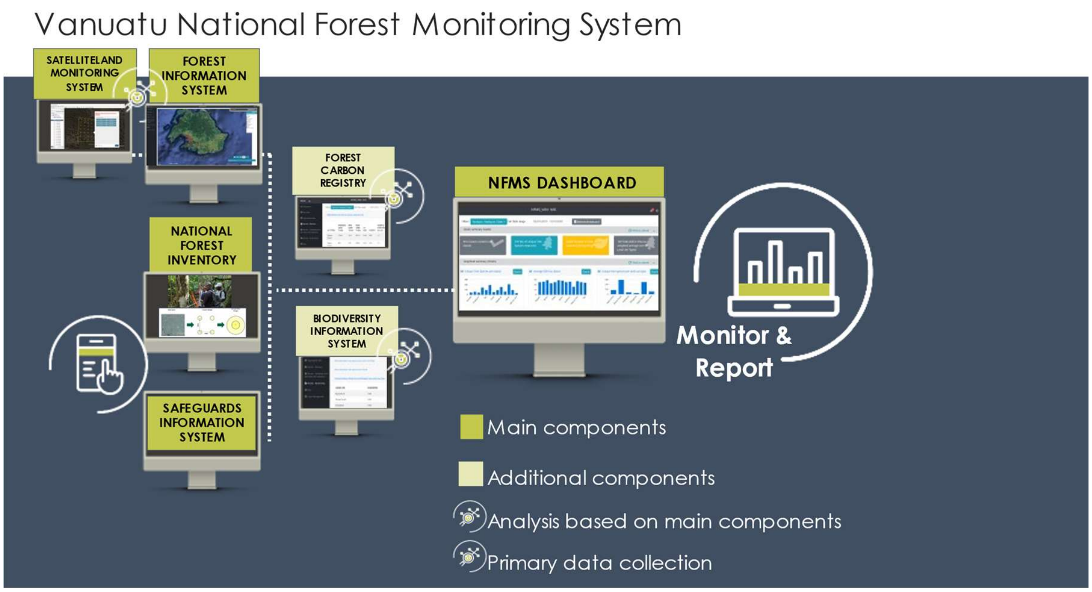


Figure 6: Framework for the NFMS for REDD+ in Vanuatu

It is structured in different MRV components concerned with measurement of activity data and emissions factors of the forest resources in Vanuatu, information system components allowing to process and analyse the measured and monitored information, and a reporting component which aggregates and presents the analysed information in a way to allow reporting for various purposes.

The Satellite Land Monitoring System (SLMS) is linked to a web-based Forest Information System (FIS). The SLMS provides a standard process to periodically assess remote sensing images to generate estimates of change between the defined land classes (i.e. Activity Data), while the FIS provides, in a web-based database environment, the analysis and aggregation tools needed to report forest and other land use change information for a defined period.

The National Forest Inventory (NFI) was designed and implemented under the supervision of the Department of Forestry between 2019 and 2021. Among many other parameters, the NFI collects all of the information needed on forest and other land use carbon stocks. The NFMS database then provides the analytical tools relevant for analysing and reporting the aggregated Emission Factors (EF). The Forest Carbon Registry presents carbon stock information while the emission factors are directly linked with the FIS.

The Safeguard Information System (SIS) is a platform to collect and manage information on how REDD+ safeguards (Cancun Safeguards) are being addressed and respected in the next phase of REDD+ implementation in Vanuatu.

The NFMS Dashboard is the central monitoring and reporting platform of the system. The dashboard is a web application which transparently reports specific results from the other components in a dashboard which can be used then by national and sub-national stakeholders for reporting purposes. The Key Performance Indicators currently implemented in the dashboard refer to REDD+ requirements such as SLMS based Activity Data, NFI data, emission factors and national FRL. However, more indicators can be integrated based on the specific needs of stakeholders. For instance, a separate biodiversity information system has also been developed which monitors specific biodiversity indicators. The dashboard also has a geo-spatial mapping system which allows to assess the processed information of the different components also spatially and on sub-national (island) levels and it flexible allows users to integrate also new spatial information into the system.

The NFMS dashboard and the web-based databases explicitly allow the creation of multiple user login pathways and dynamic analysis tools. Data is fed from the NFI or the SLMS/FIS with the ambition for the system to serve as a broader land use information portal, beyond REDD+ requirements. This also includes ways for project-level REDD+ and other land-based carbon projects to use the NFMS and therefore nest their projects within the national program.

6 Methodology used to construct the FRL

6.1 Activity Data

6.1.1 Sampling design

Sample plots are evenly distributed over the country in a systematic grid with 1.5km distances. This grid allowed for integration with the NFI grid (3 km plot resolution), and the amount of sample plots a priori seemed sufficient to provide results with an acceptable level of accuracy. Table 5 shows the total number of plots over the country for different grid distances. The grid of 1.5km was selected for the analysis.

Table 5: Grids and number of sample plots

GRID DISTANCE	NUMBER OF POSSIBLE SAMPLE PLOTS
3 x 3 km – basic NFI grid	1132
2 x 2 km	3062
1.5 x 1.5 km	**5447**
1 x 1 km	12216
750 x 750 m	21706
500 x 500 m	48775

Each Activity Data sample was taken from a rectangular plot of a length of 100x100m. In each Activity Data sample plot, there were 7x7m subplots to serve as visual support for improved land cover assessment, particularly in assessing percentages of land and canopy cover (Figure 7).

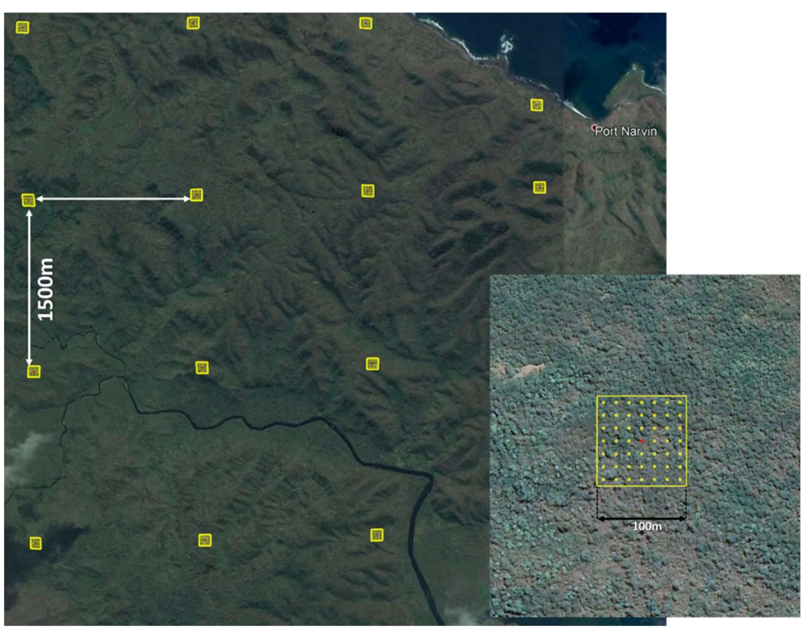


Figure 7: Illustration of the Activity Data sampling grid and the distance between sample plots.

Landsat and Sentinel imagery were used in Google Earth Engine. Further, very-high resolution images from CNES Airbus, Digital Globe, Bing Maps, Maxar, and Planet were used to provide sufficient imagery for the assessment of the baseline period.

Data from the NFI were also used to support the delineation of Activity Data and verify the results of the visual interpretation.

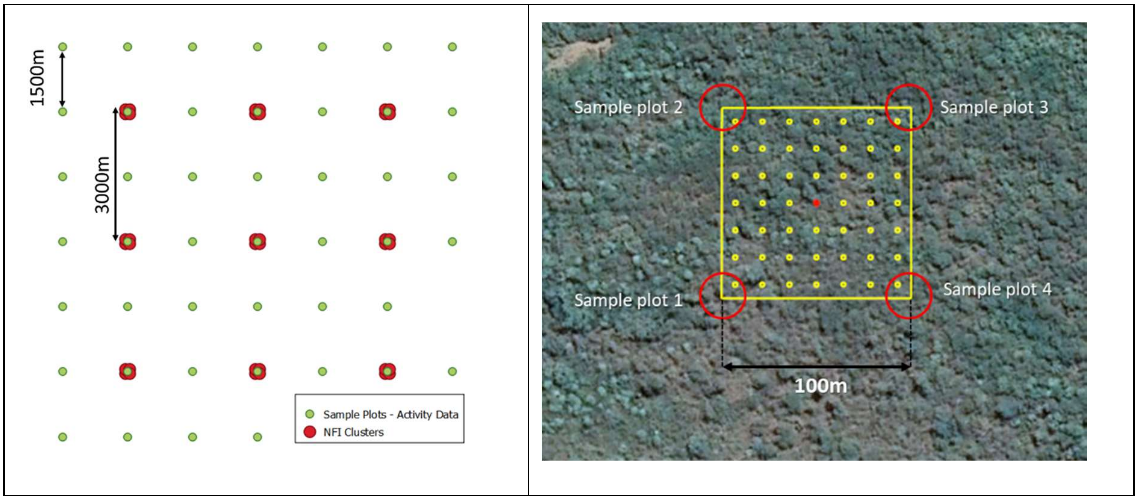


Figure 8: Integration of the AD sample plots with the NFI Clusters

6.1.2 Sample plot stratification

The systematic distribution of the sample plots formed the basis of the generation of land cover distributions for the beginning of the Reference Period in 2008. For the detection of changes such as deforestation or degradation, an additional procedure was applied as such activities are usually not equally distributed over the country.

The following sub-strata were created:

- One no-change stratum – where the land cover is constant during the Reference Period
- Two forest change strata – where there are indications for a certain disturbance.

The change stratum was restricted to areas having likely experienced forest loss, (i.e. forest degradation or deforestation). This stratification procedure was carried out on monthly composite stacks of Landsat imagery using the Continuous Degradation Detection (CODED) algorithm[17]. This resulted in a spatially explicit layer where forest changes were considered probable. Within this area the grid for the sampling was densified using the systematic grid of 750x750m. Figure 9 illustrates the location of the 750x750m grid within the likely change stratum across the country (left) and zooming into a location on the island Erromango (right).

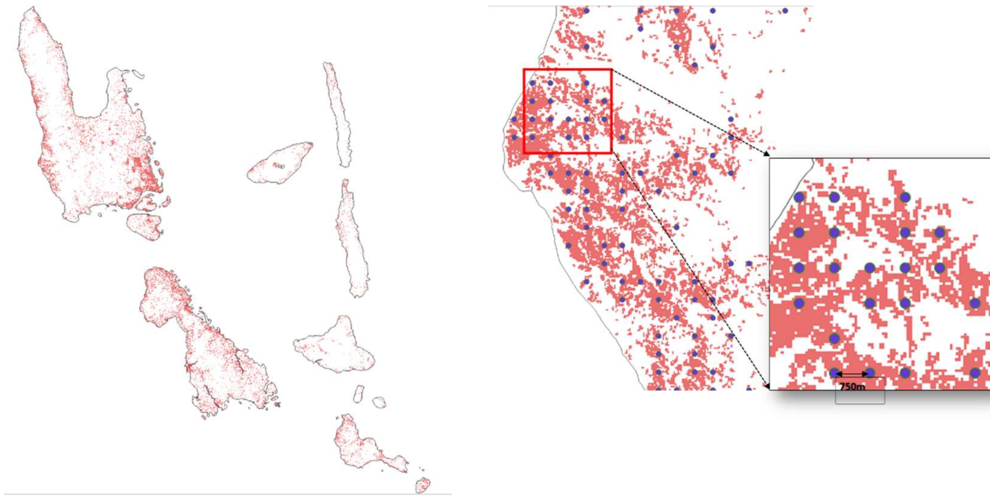


Figure 9: Densified grid change detection grid with a distance of 750 x 750m between plots (blue dots) located within the red areas indicating disturbance as a result from the CODED algorithm.

For some islands, the described change detection approach resulted in low accuracies for change detection due to a small number of detected change events. For these, a second points grid for visual interpretation was introduced in a 375 x 375m configuration, again within areas of likely land cover change. The final number of sample plots for AD quantification is therefore 15,426 as shown in Table 6.

Table 6: Summary of sample plots per stratum for Vanuatu

Stratum	Number of sample plots	Island
Stable stratum – 1500 x 1500m basic grid	4,618	All islands
Basic change stratum – 750 x 750m	2,171	Aneityum Ambae Efate Epi Espiritu Santo Maewo Tanna
Extended stable stratum – 750 x 750m	5,563	Ambrym Erromango Gaua Malekula Pentecost Vanua Lava
Basic change stratum 375 x 375m	3,074	idem
Total	**15,426**	

6.1.3 Land cover assessment procedure

Assessment of the sample plots was done using Collect Earth (CE) in a customized form focused on the land cover types, deforestation and disturbance. The preparation of the sample point grid was done using QGIS by intersecting the regular grids with the island. Seven attributes were assessed for each sample plot as presented in Table 7.

Table 7: Assessed land cover attributes

Gross Category	Detail
Land cover 2018	• IPCC Tier 1 level • Detailed Vanuatu specific land cover types
Image type use	e.g., Digital globe, WorldView2
Image date	Year, month, day
Land use change	• If land use change exists • Land use change type • Year of land use change • Forest type before deforestation event
Canopy cover in percentage and canopy cover type	0 to 100%; Type: random, linear, grouped, sparse
Disturbance	▪ Type – level 1: natural or anthropogenic ▪ Type – level 2: detailed description ▪ Forest type change ▪ Year of disturbance
Area of the plot affected.	Percent of the plot affected

6.1.4 Hierarchical rules and disturbance types

Since the assessment of land cover focused on a sample plot of 1ha in size (100x100m), some plots showed more than one land cover type present on the plot (mixed land covers). This was especially challenging in areas where Cropland occurred, close to villages and where disturbance is present. To avoid any confusion in the assessment and to create a clear guideline on how to deal with such situations a list of priority classes was established. These rules are presented in Table 8 following guidance in the literature[18].

Table 8: Hierarchical rules for land cover determination

Priority	Land class	Min. Cover in %
1	Settlement	20
2	Cropland	20
3	Forest	20
4	Grassland	20
5	Wetland	20

If the land use was classified as Forest land at one given point during the Reference Period, a disturbance event could be identified in a subsequent period. Disturbances are considered changes of land use type that do not classify as land use change but happen within the forest category as per the IPCC land cover class. The causes of forest disturbances are classified as natural or anthropogenic causes in Table 9.

Table 9: Hierarchical rules for land cover determination

Natural causes	Anthropogenic causes
Cyclone/wind	Agriculture
Fire	Fire-wood collection
Erosion	Logging/Harvest
Invasive species (e.g. Big leaf/ *Meremia*)	Infrastructure
Other natural causes	Livestock
	Other anthropogenic causes

6.1.5 Area estimation by the sample-based approach

The area of change from the sample-based approach was calculated following IPCC guidance (2006, Vol 4, Ch.3, Table 3A 3.1), where each plot represents a proportion *p* of each land cover class *i*

$$\boldsymbol{p_i = n_{i/n}}$$

Equation 1

where

n_i is the total number of sample plots located in a land cover class i

n is the total number of points across all land use classes and strata

Using the are representation of each plot $p_{i,}$ the estimated area of each land use (or land use change) category A_i was calculated using Equation 2:

$$A_i = p_i * \mathrm{A}$$

Equation 2

where

P_i is the number of plots located within the given stratum I from **Equation 1**, and

A is the total land area of Vanuatu

The final area of each stratum was determined by the area of the degradation stratum (375x375m), which is calculated using the CODED algorithm. To obtain the "normal grid" area, the degradation area is discounted from the total area. The total land area represented (i.e. the total land area of Vanuatu which amounts to 1,289,000 ha), the number of plots and the area representation of each plot are presented in Table 10 for both sampling grids used in the assessment.

Table 10: Area representation per plot and stratum

Stratum	Total area (ha)	Plot count	Area representation of each plot (ha)
S1 – degradation stratum	116,570	2,175	53.6
S2 – Stable Forest stratum	599,708	2,777	215.9
S3 – degradation stratum – increased resolution (375m)	56,889	4,114	13.8
S4 – Stable Forest stratum – increased resolution (1.5km + 750m grid)	450,499	6,364	70.8

The sample-based area estimation shows that Vanuatu has a land area of just more than 1.2 million hectares, with 926,513 ha or 76% of the country covered by natural forests (Table 11). Cropland represents the second largest land use with 156,812 ha or 13% of the national land area. Grasslands predominately occur on the islands Efate and Espiritu Santo and cover approximately 3% of the entire land cover of Vanuatu.

Table 11: Land use in Vanuatu in the year 2018.

Land Cover class	N° plots	Area (ha)	Standard error (± ha)
Cropland	2,332	156,812.15	± 3,542.8
Forest	10,677	926,513.13	± 4,545.5
Grassland	871	41,197.11	± 2,283.3
Other Land	1,081	76,491.32	± 2,525.2
Settlements	349	17,930.10	± 1,471.1
Water Body	41	3,719.89	± 509.4
Wetlands	11	1,003.39	± 264.1
Total	**15,362**	**1,223,667.10**	

The FRL is concerned with transitions from or to the forest classes (i.e. deforestation and enhancement) or, for the case of forest degradation, transitions within the forest class (i.e. conversion of Dense forest to Open forest). The resulting area estimations for recorded land use transitions (Activity Data) are presented in Table 12.

Table 12: Forest cover and land use change statistics. Reported numbers are annual averages over the Reference Period 2007-2018.

Type	Land Cover before conversion	Land Cover after conversion	Area (avg. ha per year)	N° samples	Standard error (avg. ha per year)
Deforestation	DF	Cropland	846	106	± 59.4
	OF	Cropland	837	124	± 62.2
	DF	Grassland	144	23	± 31.5
	OF	Grassland	142	22	± 30.9
	DF	Settlement	50	7	± 17.8
	OF	Settlement	183	34	± 37.7
	DF	Other land	65	12	± 23.1
	OF	Other land	117	25	± 32.8
Degradation	DF	OF	2164	238	± 66.0
Enhancement	Cropland	OF	154	17	± 27.3
	Grassland	OF	23	5	± 15.1
	Other land	OF	58	12	± 23.1

The average annual mean and standard error is calculated by dividing the total change area detected by the number of years (10) amounting to the Reference Period. Uncertainty metrics (standard error) relate to the number of sample plots located within each land use class. Details about the calculation are provided in Section 8 on Uncertainty Analysis.

Mangroves constitute one of the forest types of Vanuatu. However, mangroves occur only in a narrow corridor along the coasts of Efate and Malekula. Due to their uneven distribution, the sample-based approach adopted by the NFMS, did not produce reliable results to estimate the total size of the mangrove forest stratum. Rather, the mangrove stratum was spatially explicitly delineated using high resolution Google Earth images from the year 2018 and the national area covered by mangroves was estimated at 1727 ha. This visual delineation of mangroves served to evenly distribute the 53 NFI clusters located in the Mangrove stratum. Hence, emissions factors exist for mangroves degradation or potential conversions of mangroves to other land uses.

However, concerning Activity Data, the sample-based approach deploying visual interpretation of 31 plots did not show any land use changes in the Mangrove stratum. Hence, emissions from mangroves are not represented in this FRL. As such mangroves are included in the land use statistics as forest in Table 11 in but they are not represented by the numbers for deforestation and forest degradation in Table 12 as no change activity was detected in this stratum.

6.1.6 Deforestation

Annual land use change dynamics across the Reference Period are shown in Figure 10 for deforestation. This graph represents aggregations across multiple detailed land use transitions summarized to deforestation. Individual land use transitions aggregated in this graph include conversion of dense and Open forest to Croplands, Grasslands, Settlements and other lands as listed in Table 12. The FRL is ultimately calculated using this averaged data (i.e. the straight line), rather than annualized Activity Data.

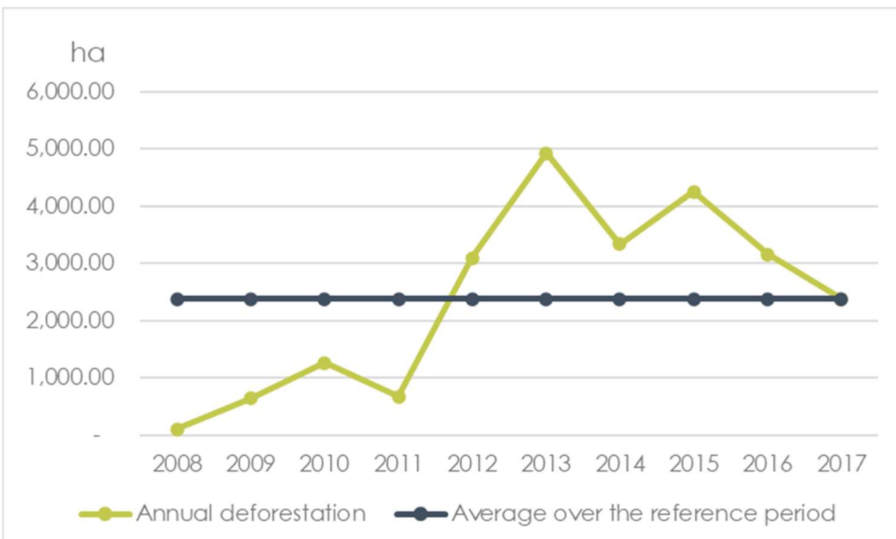


Figure 10: Deforestation dynamics and average deforestation over the Reference Period

6.1.7 Forest degradation

Annual land use change dynamics across the Reference Period are shown in Figure 11 for forest degradation.

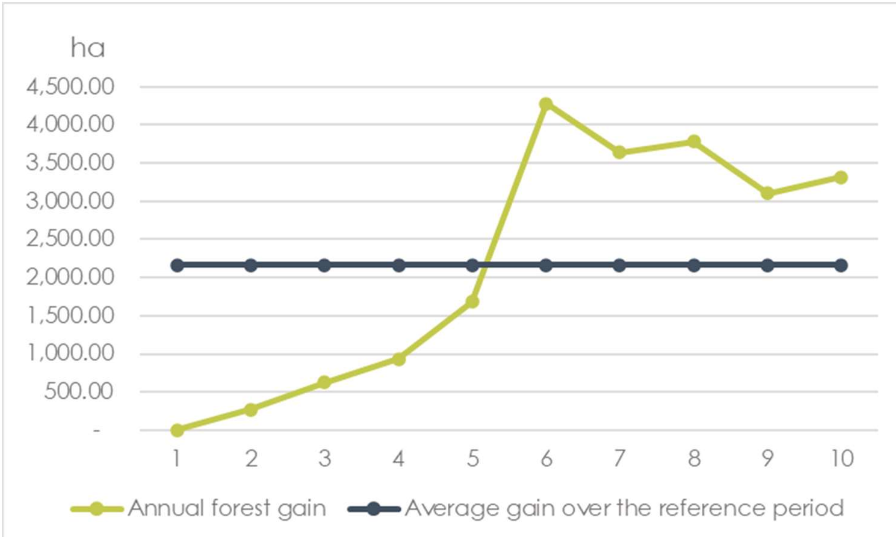


Figure 11: Forest degradation dynamics and average deforestation over the Reference Period

6.1.8 Forest enhancement

Annual land use change dynamics across the Reference Period are shown in Figure 12 for carbon stock enhancement. Individual land use transitions aggregated in this graph include conversion of Croplands, Grasslands and other land to Open forest as listed in Table 12.

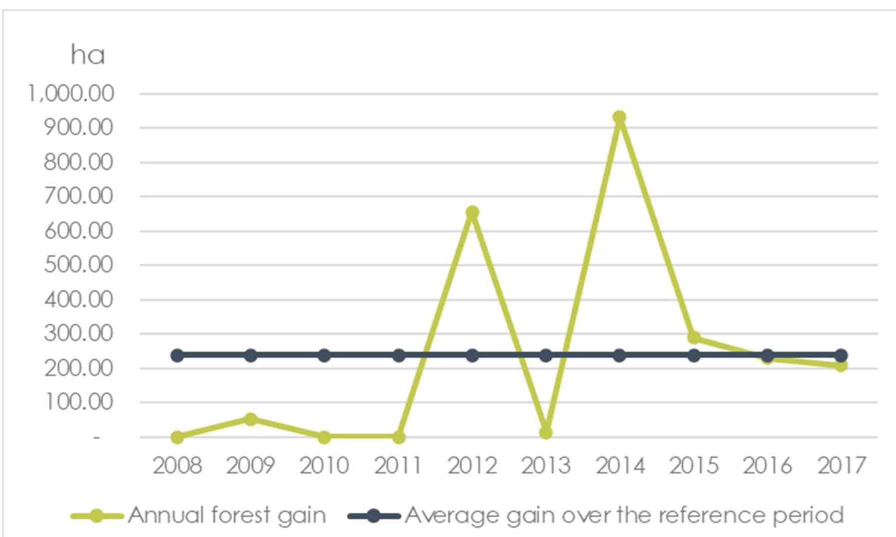


Figure 12: Forest enhancement dynamics and average forest enhancement over the Reference Period

6.2 National Forest Inventory

Biomass stocks for both Open and Dense forests are calculated from the National Forest Inventory (NFI) that was conducted between May 2018 and November 2021 by the Department of Forestry, Vanuatu. The NFI is summarised in Section 6.2.1 to 6.2.3 and detailed further in *The National Forest Inventory Report*. However, non-forest biomass stocks were not the focus of this inventory and therefore above ground biomass stocks for each non-forest land class were taken from the IPCC guidelines (IPCC, 2006, 2019) where available as described in Section 6.3.

6.2.1 NFI Sampling design

Emission factors for Open and Dense Forest were derived from the NFI. The distribution of sample clusters for the NFI in Vanuatu follow a systematic grid of 3x3 km where on each point of the grid, a cluster of four sample plots are located, distributed in the form of a square with 100m between them.

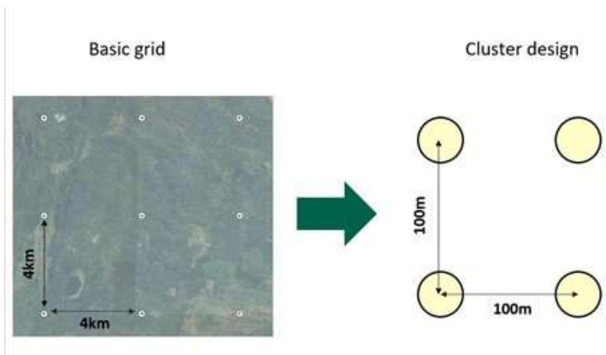


Figure 13: Distribution of the clusters on a systematic grid.

A total of 1240 clusters covered the main islands in Vanuatu distributed across all land cover types. The design of the sample plots enables meeting the forest inventory objectives to sample the following items:

- Above ground biomass
- Regeneration
- Dead wood (standing and lying)
- Litter

The sample plot design consists of concentric circles where trees with different DBH ranges are measured inside separate concentric circles to increase measurement efficiency. The sample plot design of the NFI in Vanuatu consists of a circular plot with three concentric circles:

- 1st circle with r = 3m: measuring all trees with DBH between 5-10cm
- 2nd circle with r = 6m: measuring all trees with DBH between 10-20 cm
- 3rd circle with r = 12m: Measuring all trees with DBH > 20 cm

Using the radius always implies measurements of 0m to the radius, thus the circles are overlapping.

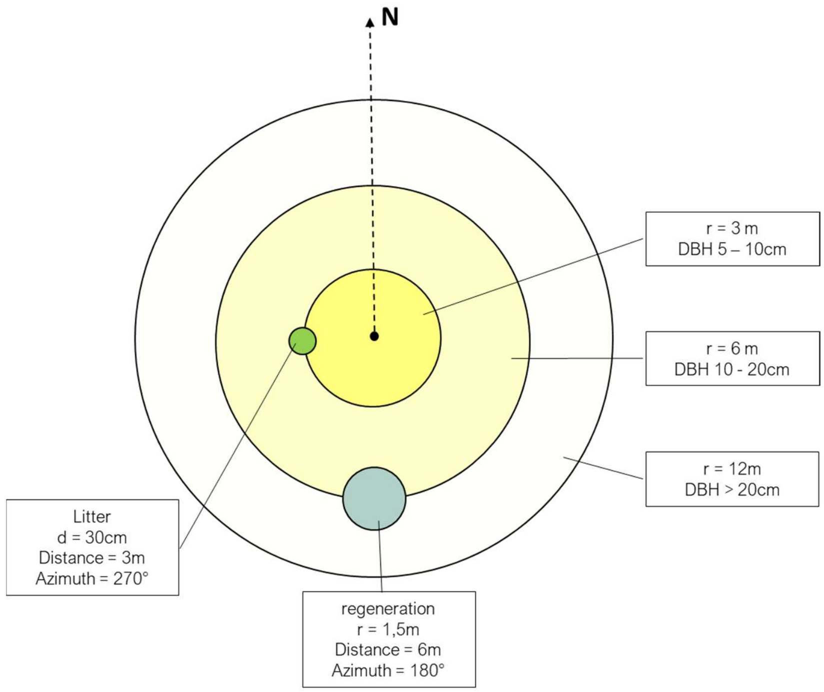


Figure 14: Graphical presentation of the concentric circles forming a plot subdivided into subplots.

The subplots of litter and regeneration are included in the circles of the tree biomass measurements.

- **Regeneration plot:** The regeneration is measured on a sub-plot in each of the plots in the cluster. The sub-plot for the regeneration is a circular plot with r = 1.5m. It is located on 6m distance from the center of the sample plot and azimuth of 180°.
- **Litter plot:** Litter is measured is a subplot with a diameter of 30 cm located 3m from the plot center and an azimuth of 270°.
- **Down dead wood:** Additionally, downed dead wood is also recorded on the full area of the sample plot, using the same rules as for standing trees.

The analysis team estimated the biomass of individual trees based on NFI data using a pan-tropical biomass equation[19] with tree DBH, tree height and wood density as input parameters.

Tree height was estimated using the allometric Equation 3 relating DBH and tree height (H):

$$H = -9.083455171 + 6.595813419 * LN(DBH)$$

Equation 3

The height function presented in Equation 3 is specifically developed for Vanuatu. The measured tree heights and respective diameters were plotted and the trendline used as function to model the height of all trees which heights were not measured (R^2=0.884).

All stumps encountered during the field inventory, as well as standing dead trees with broken crowns, have measured heights from the field teams. For this reason, no separate model is required for these tree categories.

Above ground biomass (AGB) is calculated separately for standing living trees, standing dead trees (intact and broken) and stumps. The allometric model presented in Equation 4[19] was used to calculate AGB of individual trees, where AGB is the aboveground biomass in kilograms, DBH is the tree diameter at breast height in cm, H is the tree height in m, and ρ is the tree species-specific wood density.

$$AGB = 0.0673 * (\rho * H * DBH^2)^{0.976}$$

Equation 4

The sample plots were made up of concentric circles, where only trees of a specific DBH range are measured. The aggregation of the tree level attributes to the plot level was attained by tree specific expansion factors derived from the concentric circle areas. By multiplying the expansion factor with the tree level attributes, the attributes are scaled up to hectare level, thus making the attribute independent from the respective concentric circle and enabling the plot level aggregation. The scaled attributes of each tree on a plot are summed, resulting in the aggregated plot values on a per hectare basis. The following tree level attributes are aggregated on the plot level:

- Biomass: t/ha
- Number of trees: 1/ha

Step 1: Expansion factors

The concentric circle area corresponding to a tree's DBH (a_{CC}) is used to calculate its expansion factor (f_{EF})as per Equation 5 to scale up the tree attributes to the reference area of one hectare, as follows:

$$f_{EF} = 10000/a_{CC}$$

Equation 5

Step 2: Aggregation

Building on the expansion factor, aggregation combines attributes to the plot level as per Equation 6

$$attr_p = \sum_{i=1}^{n_t} attr_{t_i} * f_{EF_{t_i}},$$

Equation 6

with $attr_{t_i}$ as the tree level attribute, to be aggregated to plot level, $f_{EF_{t_i}}$ as the respective expansion factor of the individual tree, n_t as the number of trees on plot p and finally $attr_p$ as the plot level attribute. In the case of tree count (n_plot), $attr_{t_i} = 1$.

Table 13 presents attributes to aggregate different subplots to plot level.

Table 13: Attributes of concentric circles of sample plots

Radius [m]	Min DBH (>=) [cm]	Max DBH (<) [cm]	Area [m²]	Expansion factor [m²/ha]
3	5	10	28	357.143
6	10	20	113	88.496
12	20		452	22.124

For aggregating plot level information to clusters, the cluster level attributes are calculated as the mean of the plot level attributes, of all plots making up the cluster as per Equation 7. Since some plots were inaccessible or showed differences in land cover (presence of steep rock faces or lakes on parts of a plot) the mean is weighted by the percentage of the accessible area of each plot.

$$attr_c = \frac{\sum_{i=1}^{n_p} attr_{p_i} * p_{p_i}}{\sum_{i=1}^{n_p} p_{p_i}},$$

Equation 7

with $attr_{p_i}$ as the plot level attribute, to be aggregated to cluster level, p_{p_i} as the corresponding percentage of intended area covered by the plot, n_p as the number of plots making up the corresponding cluster (up to 3 but possibly less due to inaccessibility) and $attr_c$ as the weighted average cluster attribute.

6.2.2 Other biomass pools

The NFI provides data for the calculation of the carbon pools above-ground live biomass (AGB), below-ground live biomass (BGB) and dead organic matter (DOM); comprising both standing and lying deadwood) as well as stumps and litter in forest land. BGB is calculated from AGB using root-to-shoot ratios (R:S) from [12], [13] and varying with land cover types as per Table 14. To be conservative, BGB of cropland is not included due to the absence of applicable R:S ratios from the IPCC guidelines for this land cover class.

Table 14: Root-to-Shoot factors used to calculate BGB from AGB.

	R:S values (< 125 t dm /ha, AGB)	**Reference**
Open forest, Dense forest,	0.323	IPCC 2019, Table 4.4, Tropical moist, Asia, Natural
Grassland	1.6	IPCC 2006, Table 4.4, Tropical Grassland
Other land, Settlements	0.4	IPCC 2006; Table 4.4, Tropical Shrubland

The carbon stored in litter is calculated on a plot level. On each plot, if any litter is present, the green (wet) weight of the litter on a circular plot with a radius of 0.15 m weighed (in grams). To estimate the biomass and, ultimately, the carbon stored the litter (in tons/ha), the fresh weight of litter needs to be multiplied by a number of factors which have been provided by [20].

First, a litter weight conversion factor ($f_{L_{dry}} = 0.307$ used to convert the weight of wet litter to dry weight as per Equation 8.

$$w_{L_{dry}} = w_{L_{wet}} * f_{L_{dry}} = w_{L_{wet}} * 0.307$$

Equation 8

A weight factor $f_{L_t} = \frac{1}{1000000}$ is applied to convert the weight from g to t as per Equation 9.

$$w_{L_{dry\ t}} = w_{L_{dry}} * f_{L_t} = w_{L_{dry}} * \frac{1}{1000000}$$

Equation 9

An area factor $f_{L_{area}} = \frac{10000}{\pi * 0.15^2}$ serves to scale the weight from the plot size to hectare as shown in Equation 10**.**

$$w_{L_{dry\ t/ha}} = w_{L_{dry\ t}} * f_{L_{area}} = w_{L_{dry\ t}} * \frac{10000}{\pi * 0.15^2}$$

Equation 10

The carbon content in the litter is expressed by $f_{L_c} = 0.4$ to convert the dry biomass weight to carbon as per Equation 11.

$$w_{L_c} = w_{L_{dry\ t/ha}} * f_{L_c} = w_{L_{dry\ t/ha}} * 0.4$$

Equation 11

6.3 Carbon stock and flow data

With this distribution, a total of 1240 clusters cover the main islands in Vanuatu distributed across all forest land cover types. Owing to the NFI's focus on forest biomass, the FRL relies on IPCC default values for cropland and grassland. As IPCC default values are not available for settlements and other lands, for these the FRL of Vanuatu relies on values reported by the Emissions Reductions Project Document (ER-PD) of Indonesia. An overview of above-ground carbon stocks derived from the NFI is provided in Table 15 whereas details for individual carbon pools are presented in ANNEX 1: Details of Biomass Pools. The data is also contained in the spreadsheet workbook[6] which is supplementary files to this report.

BGB was calculated from AGB using the shoot-root ratio of 0.323 with a SE of the mean of ±0.73 (or 35% of the mean) applicable to moist tropical forests in Asia with a biomass <125 t DM/ha as recommended by [13], following Equation 12[7]. This uncertainty level is only required for the uncertainty analysis presented in section 7.

$$\mathrm{BGB} = \mathrm{AGB} * 0.323 \pm 0.073$$

Equation 12

[6] See supporting workbook *tab EF, lines 8-14*

[7] See supporting *workbook tab EF, line 55*.

Table 15: Biomass stocks recorded in the six land cover classes

Land cover class	Mean Aboveground Biomass (tdm/ha)*	N° samples	Coefficient of Variation (%)	Source
Dense forest	121.1	289	52%	NFI
Open forest	86.1	222	64%	NFI
Cropland	10.0	Not available	38%	IPCC 2019
Grassland	13.2	Not available	38%	IPCC 2006
Settlements	14.8	Not available	38%	MoEF 2018
Other	34.3	Not available	38%	MoEF 2018

Source: IPCC 2019, CH5, Table 5.9, Annual cropland; IPCC 2006, CH6, Table 6.4, Tropical moist & wet; MoEF, 2018 - Indonesia: Biomass stocks for settlements taken from the settlements land class; Other land is composed as the average of categories "dry shrub", "wet shrub", and "transmigration areas".

6.4 Emission and removal factors

Biomass estimates are converted to carbon values using the carbon fraction of dry matter as recommended by the IPCC ([12]; Volume 4, Chapter 4, TABLE 4.3) following Equation 13[8] where the uncertainty level is only required for the uncertainty analysis presented in Section 7.

$$Carbon\ Content\ =\ Dry\ biomass\ *\ 0.47 \pm 0.015$$

Equation 13

Carbon stock values were converted to tCO_2e following Equation 14[9]:

$$CO_2\ eq\ =\ C\ *\ (44/12)$$

Equation 14

Loss or gain in biomass and associated EF have been calculated from the difference in carbon stored in the biomass before and after the conversion. The relevant conversions and biomass stocks and resulting emission factors are presented in Table 16.

[8] See supporting *workbook tab EF, line 73ff*
[9] See supporting *workbook tab FRL, line 4*

Table 16: Biomass, emissions and removals factors of all land cover transitions per hectare.

Type	Conversion	Biomass before conversion (tdm/ha)	Biomass after conversion (tdm/ha)	Biomass loss or gain (tdm/ha)	Emissions factors (tCO_2e/ha)
Deforestation	DF to Cropland	186.20	10.00	176.20	303.65
	OF to Cropland	132.70	10.00	122.70	211.45
	DF to Grassland	186.20	34.30	151.90	261.77
	OF to Grassland	132.70	34.30	98.40	169.58
	DF to Settlement	186.20	20.77	165.43	285.08
	OF to Settlement	132.70	20.77	111.93	192.89
	DF to Other	186.20	47.99	138.20	238.17
	OF to Other	132.70	47.99	84.70	145.97
Degradation	DF to OF	186.20	132.70	53.50	92.20
Enhancement	Cropland to OF	10.00	132.70	-122.70	-211.45
	Grassland to OF	34.30	132.70	-98.40	-169.58
	Other land to OF	47.99	132.70	-84.70	-145.97

7 Forest Reference Level

For the Reference Period, carbon biomass losses (emissions) and gains (removals) related to anthropogenic Deforestation, Forest Degradation and Carbon Stock Enhancement were determined following the basic IPCC equation (IPCC, 2006; Equation 15)[10].

$$E = AD \; x \; EF$$

Equation 15

Where:

E = Emissions in tCO_2e/yr

AD = Activity Data (in ha/yr)

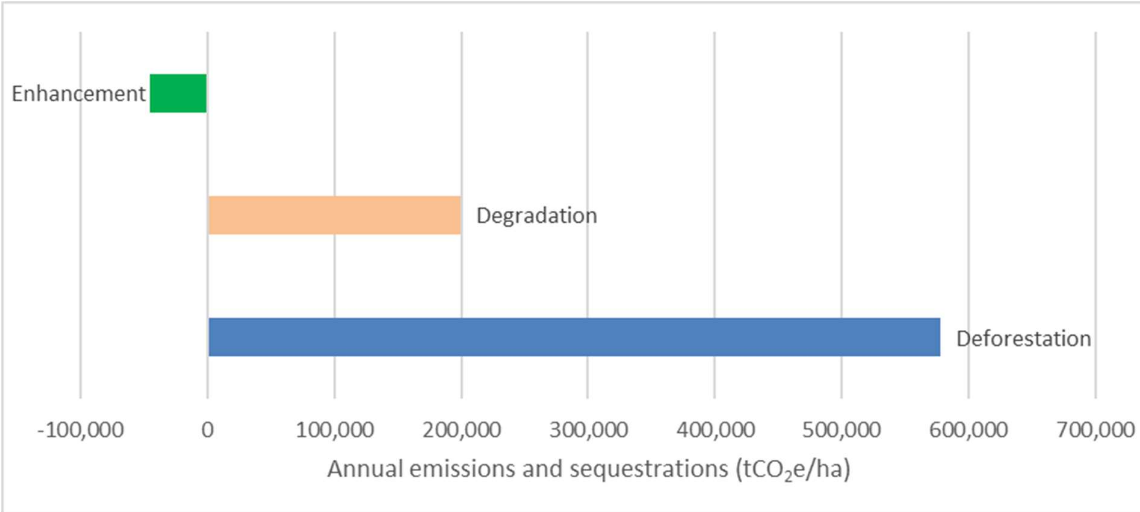
EF = Emissions Factor (Removals Factor, in the case of enhancement of carbon stocks; in tCO_2e/ha)

Emissions are calculated on an annual basis and data are organised by national land use category, forest type and carbon pool. Table 17 provides an overview of area and emissions factors per land use conversion class while Figure 15 and 16 represent the FRL emissions graphically. Multiplication of AD and EF results in the total FRL emissions of 732,441 tCO_2e/year during the Reference Period

Table 17: The proposed FRL as composed of AD and EF.

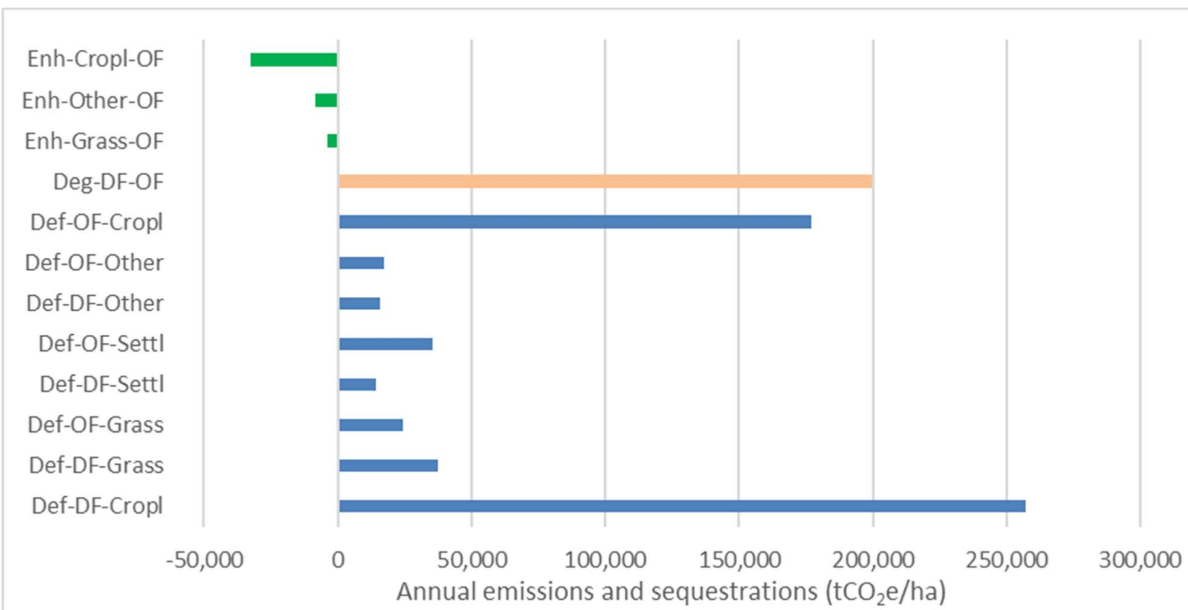
Type	Conversion	Area (Avg. ha/year)	Emissions factors (tCO_2e/ha)	Emissions (t CO_2e/year)	Aggregated Emissions (t CO_2e/year)
Deforestation	DF to Cropland	846	304	256,883	577,733
	OF to Cropland	837	211	176,981	
	DF to Grassland	144	262	37,646	
	OF to Grassland	142	170	24,152	
	DF to Settlement	50	285	14,190	
	OF to Settlement	183	193	35,234	
	DF to Other	65	238	15,549	
	OF to Other	117	146	17,097	
Degradation	DF to OF	2,164	92	199,502	199,502
Enhancement	Cropland to OF	154	-211	-32,476	-44,794
	Grassland to OF	23	-170	-3,870	
	Other land to OF	58	-146	-8,448	
Net emissions across all sources				**732,441**	

[10] See supporting w*orkbook tab FRL, lines 7ff*



Enhancement is represented in green, degradation in orange, and deforestation in blue.

Figure 15: A graphical representation of the annual average emissions from each of the three REDD+ activities in the scope of this FRL



Enhancement is represented in green, degradation in orange, and deforestation in blue.

Figure 16: A further break down of the emission and removal sources considering the land use conversation type.

7.1 Gross emissions from deforestation

Gross Emissions for REDD+ activity Deforestation were calculated using Equation 15, the Activity Data described in section 5.1[11] and the Emissions Factors in Table 17[12]. Full calculations are found in the Workbook in the Workbook, tab “FRL”. The calculation comprises all biomass losses from Forest land converted to non-Forest land-use categories in Vanuatu.

Average annual gross emissions from deforestation (i.e. the sum of all transitions pertaining to deforestation in Table 17) amount to 577,733 tCO_2e/year over the 2008-2017 period. Emissions spiked in the year 2013 following windthrows caused by cyclones and subsequent encroachment by local population but thereafter returned to long-term average deforestation rates.

Conversions of Dense or Open forests to Cropland are the most notable sources of emissions with an average of 256,883 tCO_2e/year and 176,981 tCO_2e/year, respectively. These two conversions combined account for almost 55% of emissions calculated. Conversions to Grassland, Settlement or Other lands are also frequent.

7.2 Gross Emissions from forest degradation

The conversion of Dense forest to Open forest constitutes forest degradation as only those transitions which can be clearly attributed to human activity. Forest degradation is the second most important source of emissions (orange bar in Figure 15) with 199,502 tCO_2e/year on average over the Reference Period.

7.3 Removals from carbon stock enhancement

There are relatively small areas of forest regrowth resulting in carbon stock enhancements 44,794 tCO_2e/year on average over the Reference Period. These are dominated by transitions of Cropland land to Open forest accounting for 73% of all carbon removals, with forest regrowth in Grasslands and other lands making up for the remainder (green bars in forest reference level breakdown, Figure 16)

7.4 Net Emissions from included REDD+ Activities

The aggregate Forest Reference Level (net emissions) for Vanuatu amounts **to 732,441 tCO_2e/year**. This is represented by the sum of all the bars in Figure 15[13].

---

[11] See supporting w*orkbook Tab “AD”, expressed in ha/yr*

[12] See supporting w*orkbook Tab FRL, lines 7ff; expressed in* tCO_2e/ha

[13] See supporting workbook, tab Figures, Figure 1

8 Uncertainty Analysis

Uncertainty analysis encompasses statistical estimation of emission factors, Activity Data and the FRL. The objective of this section is to transparently assess and communicate the uncertainty (notably the statistical random sampling error) associated with the FRL, and its underlying components. The calculations presented here follow guidance provided by IPCC (2006, Vol.1, Ch 3).

8.1 Emissions factors

The uncertainty of the estimated mean of a parameter (e.g. biomass) is calculated on the stratum level and for the entire country from the weighted averages of the parameter on the cluster level.

The procedure involves five steps:

In step 1, the weighted average of the parameter in the stratum is built as per Equation 16:

$$\overline{y_s} = \frac{\sum_{i=1}^{n_c} y_i w_{c_i}}{\sum_{i=1}^{n_c} w_{c_i}},$$

Equation 16

with y_i as the cluster level attribute, to be aggregaterd to stratum level, w_{c_i} as the corresponding weight (the sum of the area percentage surveyed on each of the plots within a cluster), n_c as the number of clusters in the corresponding stratum and $\overline{y_s}$ as the weighted average of the parameter. This equation is a derivative of Equation 7 with the notation adjusted to fit the equations in the following steps.

In step 2, the weighted variance of the parameter in each stratum is calculated using Equation 17:

$$v(\overline{y_s}) = s^2(\overline{y_s}) = \frac{\sum_{i=1}^{n_c} (y_i - \overline{y_s})^2 * w_i}{\sum_{i=1}^{n_c} w_i}$$

Equation 17

In step 3, the margin of error (MOE) is calculated using Equation 18:

$$MOE_s = t * SE_s = t * \frac{s(\overline{y_s})}{\sqrt{n_c}} = t * \frac{\sqrt{v(\overline{y_s})}}{\sqrt{n_c}}$$

Equation 18

The margin of error is calculated from the t-value (t) and the standard error of the mean (SE_s), which depends on the number of clusters (n_c) and the standard deviation of the parameter ($s(\overline{y_s})$), defined as the square root of the parameter variance ($v(\overline{y_s})$). The t-value depends on the required level on confidence (90 %) and the degrees of freedom ($df = n_c - 1$).

Step 4: Stratum uncertainty (relative margin of error)

$$rMOE_s = \frac{MOE_s}{\overline{y_s}} * 100\%$$

Equation 19

For comparability of the uncertainties between strata, the margin of error is divided by the weighted average of the parameter and multiplied by 100. This result is the percentage of the mean, by which it can deviate 90% of the time. The threshold for the estimates to be regarded as accurate is set at 10%. The relative margin of error thus needs to lie below this.

Step 5 is the overall uncertainty calculation (weighted relative margin of error) as per Equation 20:

$$rMOE_t = t * \frac{\sum_{i=1}^{n_s} w_{s_i} * SE_s}{\sum_{i=1}^{n_s} w_{s_i} * \overline{y_s}} * 100\% = t * \frac{\sum_{i=1}^{n_s} w_{s_i} * \frac{\sqrt{v(\overline{y_s})}}{\sqrt{n_{c_s}}}}{\sum_{i=1}^{n_s} w_{s_i} * \overline{y_s}} * 100\%$$

Equation 20

In order to calculate the overall uncertainty, the weighted average of the strata's standard error of the mean (SE_s) and weighted average of the parameter ($\overline{y_s}$) is calculated by summing the product of each the values and their respective weights (w_{s_i}). The weights are calculated as the ratio between the stratum area (sum of the area of clusters (w_c) within a stratum) and the total area (sum of the area of all clusters (w_c)). The overall relative margin of error is calculated from the weighted averages of SE_s and $\overline{y_s}$.

Calculation of belowground biomass involves a sample error in AGB estimations and a statistical error of the Root-to-shoot ratio. To combine these, error propagation procedures as per the relevant guidelines are applied IPCC 2006 (Volume 1, eq. 3.1) states that where uncertain quantities are to be combined by multiplication, the standard deviation of the sum will be the square root of the sum of the squares of the standard deviations of the quantities that are added, with the standard deviations all expressed as coefficients of variation, which are the ratios of the standard deviations to the appropriate mean values Equation 21[14].

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

Equation 21

The standard error (SE) of mean biomass estimates is calculated using the regular SE equation presented in Equation 22 where SD_i is the standard deviation of biomass at the plot level *i* and *n* is the number of plots measured during the conduct of the NFI[15].

$$SE_{Mean} \frac{SD_i}{\sqrt{n_i}}$$

Equation 22

[14] See supporting *workbook tab EF, lines 55ff*

[15] See supporting *workbook, tab EF, column F*

The relative standard error SE_{rel} of was calculated using Equation 23, where SE is the standard error from Equation 22 divided by the Mean biomass content measured within each land use class i. [16]

$$SE_{rel_i l}= \frac{SE_i}{Mean_i}$$

Equation 23

8.2 Activity Data

Following the IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry recommendations [21], the sampling error of the proportion of a given class I of land cover is calculated from the proportion of plots assessed falling in the land cover i weighted by the total number of plots assessed. The 90 % confidence interval related to the area of the class i is then calculated as follows using a z-value of 1.64 (for a 90% CI of the mean) in Equation 24[17]

$$CI = \frac{Atot\sqrt{\frac{p_{i*(1-p_{i)}}}{n-1}} * 1.64}{A_i}$$

Equation 24

8.3 Uncertainty analysis of the FRL

The overall uncertainty of the FRL is assessed by applying Monte Carlo analysis. The Monte Carlo has been chosen as it allows for detailed category-by-category assessment of uncertainty, high uncertainties had been expected from the onset, the algorithms underlying the FRL calculation are complex functions and/or there are correlations between some of the activity sets, emissions factors, or both.

Thus, **the combined uncertainty of the FRL is approximately 12%** (the actual value varies slightly with each click in the worksheet as a different random number for the Monte Carlo analysis is picked). Figure 17 presents a histogram of the 1,000 iterations run for the Monte Carlo analysis.

Another way to present the results of the Monte Carlo analysis is a moving average of the result of 1000 simulation runs. The graph confirms that with 1000 runs the moving average converges to the mean value of around 720,000 tCO_2e/year (Figure 18).

[16] *See supporting workbook, tab EF, column H*

[17] See supporting *workbook tab AD, lines 7-14*

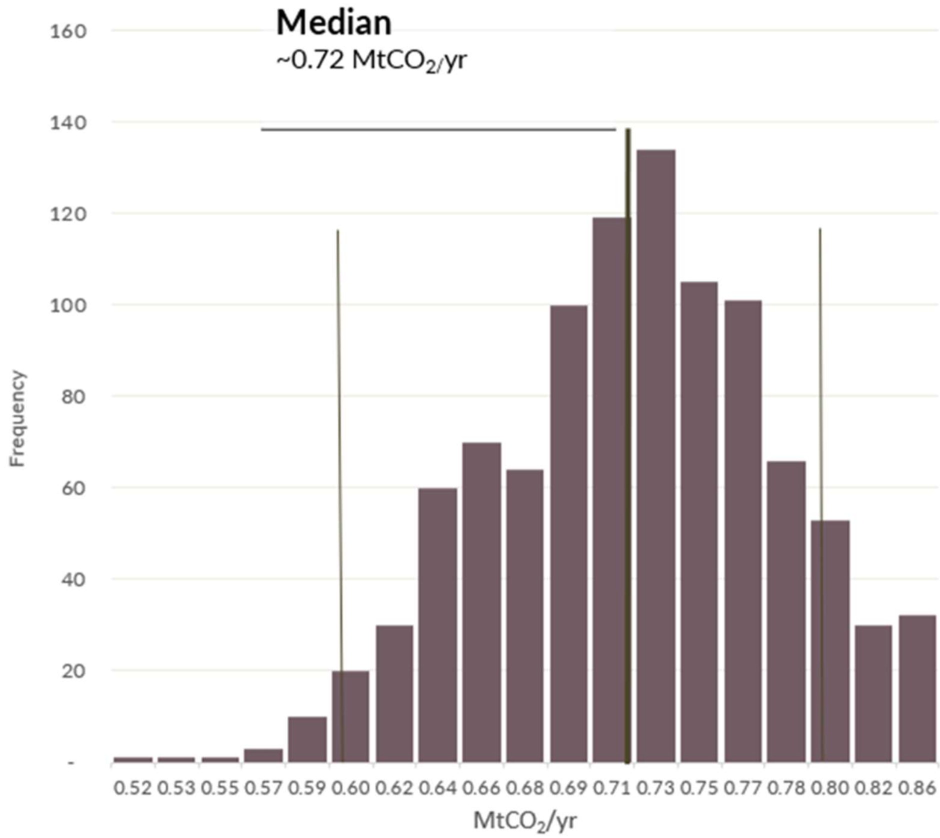


Figure 17: Histogram of the 1,000 iterations run for the Monte Carlo analysis. (Thin black bars represent the 10th and the 90th percentile, respectively, the thick bar in the centre represents the median over 1000 iterations)

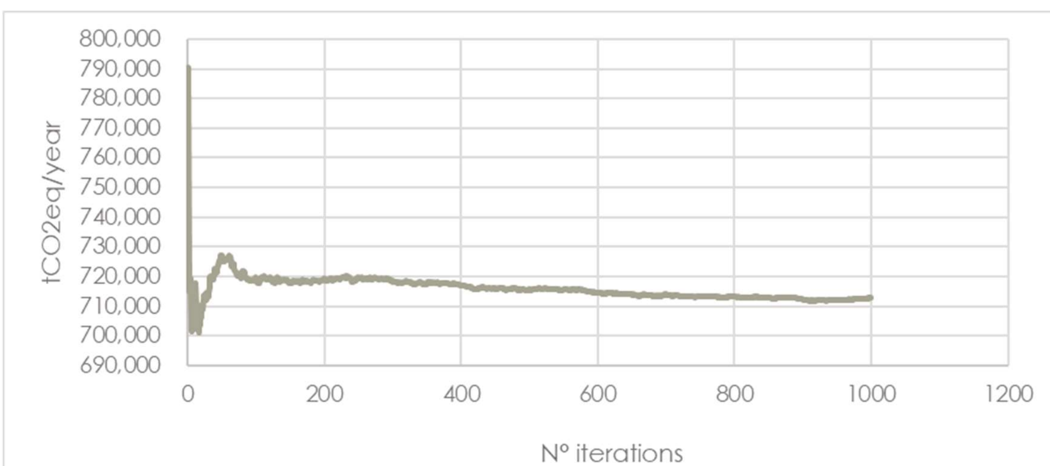


Figure 18: The moving average over the results of the 1000 simulations

9 Quality Assurance/Quality Control

Quality Assurance and Quality Control (QA/QC) consists of a set of technical routine activities to assess and maintain the quality of data as it is being compiled. QC was performed throughout the compilation of the AD and EF database and the FRL calculation with inputs from international technical experts.

Every effort was made to source the most complete, transparent and accurate data to construct the FRL. Wherever possible, published national or international datasets using internationally recognized methods were applied to ensure the highest scientific standards.

Where published national data were not available, supplementary data were collected by trusted national and international institutions specifically for the purposes of the FRL. All unpublished data are accompanied by scientific reports, raw data are available for all of the datasets used and have been checked rigorously. To ensure QC of national datasets, specialist partners conducted independent analyses to clean the data, verify its quality and remove potential sources of error. IPCC default values were only used when there were no national data available through published studies or the aforementioned long-term scientific collaborations.

9.1 QA/QC of NFI field work

QA/QC procedures form an integral part of each NFI, including the Vanuatu NFI underlying the EF calculations. The aim of this procedure is to provide a framework to ensure that the information compiled during the field work of the inventory follows TCCCA criteria as outlined in section 4.1 on good practice. The implementation of this QA/QC will improve the credibility and soundness of the NFI in Vanuatu.

9.1.1 Plausibility checks during field work

The data for the NFI Vanuatu are collected using digital field forms based on the platform OpenForis Collect Mobile and are captured on tablets. A number of errors can occur during the fieldwork, which can influence the results of the NFI. Such errors can be logical errors (where wrong codes or attributes are entered in fields that should be left empty, a DBH is entered that is too high) or it can be errors caused by misspelling or typing (comma not entered for a DBH, species name written wrong etc.).

To avoid such errors a number of plausibility checks have been coded in the OpenForis Collect field forms and are directly connected to a specific field. Two different approaches are implemented to secure a clean and correct data entry in the field:

- Code lists – as drop-down menu of attributes for selection
- Logical checks that show messages if the data is missing or inaccurate.

The code list is an option, which is programmed in the field forms used in NFI. Field crew were given the possibility of selecting the required information from a predefined list of options, thus avoiding the necessity of writing free text, which is prone to typing errors. A number of attributes are entered in this way, including all attributes that are of a descriptive nature. These attributes are listed in Table A 1 in Annex 3.

9.1.2 Logical checks

Logical checks are plausibility checks of the data that is entered. Each entered value is checked against a number of pre-defined validators and based on the outcome, a message is shown to the user. Such a message is either:

Warning message – making the user aware that the entered value might not be correct. This is not necessarily an error but a case where the user has to double check the entered value:

Error message – in the case when the entered value is incorrect or an obligatory field is left empty.

Table A 2 in Annex 3 holds a list of all the attributes where a logical validator is present and the description of the validators.

9.2 QA/QC procedures on collected NFI data

The field measurements done by the teams are part of the QA/QC as well. The QA/QC in this case includes re-measurement of a certain number of clusters and sample plots by a QA/QC team or in some cases a different field team. These re-measurements are done in different stages of the field work and serve as:

- Continuous capacity building
- Identification of typical errors in measurement procedures
- Assessment of accuracy of the measurements
- Assessment of repeatability of the measurements

9.2.1 Hot checks

A supervisor performs hot checks, or a team in charge of quality control, in the field at the same time as the field team is measuring the sample plot. It is an extended measure of capacity building and ideally should be performed directly after the training, when each team should be visited for at least 1 or 2 days. 2-3% of plots should be controlled by this procedure.

9.2.1.1 Cold checks

The team or person responsible for QA/QC attends the measured sample points with a copy of the measured data from the field teams. They repeat the measurements, either completely or using a specifically designed supervision measurement protocol. Comparison of the supervision measurements and the original field measurements then serves as the basis for the quality assessment. The results will help to identify crews or individuals with quality issues that need to be addressed. 3-5% of the clusters should be controlled by a combination of cold and blind checks.

9.2.2 Blind checks

Experts or regular crews are sent to plots without the previous crew's data or knowledge and measure the plot as if it were a new plot. Producing regular QA assessment reports in this manner provides users with the information needed to assess the repeatability of measurements and plays an important role in ensuring transparency and accountability. 3-5% of the clusters should be controlled by a combination of cold and blind checks.

9.2.3 Data analysis and QA/QC report

The goal of the analysis from blind checks is to assess the transparency and the repeatability of measurements, meaning that two different teams should get very similar measurements at the same cluster and plot. The analysis team takes this into consideration and prepares a report of the total values on the plot and cluster and the encountered inconsistencies.

9.2.4 Tolerance and completion standards

The QA/QC procedure includes the following components:

- Checks for the completeness of the data: All required fields should contain information
- Tolerance values for each of the individually measured attributes.
- For instance, tolerance values for the DBH are defined for each circle separately. For trees between 5 and 10cm the tolerance is ±6mm; for trees with DBH between 10 and 20cm a tolerance of ±10mm and for trees with DBH more than 20cm a tolerance of ±15mm
- Completion threshold – at the cluster level, a threshold of no more than 10% of the measured attributes is outside of the defined tolerances.

9.3 QA/QC of Activity Data

Due to the number of visually assessed land cover plots, not all plots could be checked for correctness of their land use classification. Therefore, a sample of 10% of the assessed land cover plots was taken to be completely re-assessed and checked for validity and correctness of the land cover (change) classification. Furthermore, all plots with identified disturbance and land use change events were subject to quality control measures and got assessed a second time. The operators were shifted to ensure the same operator would not reassess the same plots as during the initial land cover assessment. The plots subject to quality control were selected randomly using Microsoft Excel.

10 Future Improvements

Vanuatu's FRL was developed with the data that is currently available. Vanuatu will aim to improve its future FRL submissions with the availability of new data. One of the key points, to improve transparency, is to make NFI and NFMS data publicly available. Potential stepwise improvements in terms of data collection and analysis are described below.

Steps to improve the FRL

1. Performing a sensitivity analysis on the factors driving uncertainty in the FRL would allow to analytically identify the main factors relevant to improve the overall uncertainty of the FRL
2. If there are good reasons to think that deforestation will increase in the future, partitioning the Reference Period into more than one periods could allow to justify an upwards adjusted FRL.

Steps to improve Activity Data

The Republic of Vanuatu may consider the following points towards improving Activity Data:

1. Investigate pursuing a wall-to-wall mapping approach to create a land use base map and a land use change map to enable a Risk Map FRL allocation approach to encourage private sector projects to high-risk areas and to be nested in the National system.
2. Given the low prevalence of mangroves conversion, a wall-to-wall mapping approach might be beneficial (see details in the discussion on subnational FRL below

Steps to improve Emissions and Removal Factors

The Republic of Vanuatu may consider the following points towards improving Emissions and Removal Factors:

1. Continue the NFI to re-measure existing forest plot network. This will allow to estimate sequestration rates in forests remaining forests from the same source as carbon measurements
2. Densify the plots network where land-use changes have happened or may happen, particularly the conversion of Forest land to other IPCC land-use categories such as Cropland, Grassland and Settlement.
3. Include the soil carbon pool

11 References

[1] "Vanuatu National Biodiversity Strategy and Action Plan [NBSAP] 2018-2030 | PIPAP." https://pipap.sprep.org/content/vanuatu-national-biodiversity-strategy-and-action-plan-nbsap-2018-2030 (accessed Mar. 14, 2022).

[2] "Vanuatu Population (2022) - Worldometer." https://www.worldometers.info/world-population/vanuatu-population/ (accessed Mar. 14, 2022).

[3] GoV, "2020 NPHC Reports - Vanuatu Census." https://vnso.gov.vu/index.php/en/census-and-surveys/census/2020populationhousingcensus (accessed Mar. 14, 2022).

[4] "Vanuatu REDD+ Programme | Vanuatu National REDD+ Programme." http://reddplus.vu/publications/reports/ (accessed Mar. 14, 2022).

[5] "Vanuatu," *Cop23*. https://cop23.com.fj/vanuatu/ (accessed Mar. 14, 2022).

[6] "Vanuatu_Constitution_en.pdf." Accessed: Mar. 14, 2022. [Online]. Available: https://publicofficialsfinancialdisclosure.worldbank.org/sites/fdl/files/assets/law-library-files/Vanuatu_Constitution_en.pdf

[7] S. Scott, M. Stefanova, A. Naupa, and K. Vurobaravu, "Vanuatu national leasing profile: a preliminary analysis," 2012.

[8] H. J. Geist and E. F. Lambin, "Proximate Causes and Underlying Driving Forces of Tropical DeforestationTropical forests are disappearing as the result of many pressures, both local and regional, acting in various combinations in different geographical locations," *BioScience*, vol. 52, no. 2, pp. 143–150, 2002.

[9] Republic of Vanuatu, "Vanuatu National REDD+ Strategy," Port Vila, Vanuatu, 2020.

[10] B. Payne, "Community, Forest Carbon & Indigeneity: A Case Study of the Loru Project in Espiritu Santo, Vanuatu," 2020.

[11] "Vanuatu Readiness Preparation Proposal (R-PP)." Forest Carbon Partnership Facility (FCPF), Jul. 11, 2013.

[12] H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe, "2006 IPCC guidelines for national greenhouse gas inventories," 2006.

[13] IPCC, *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, vol. 4, no. 2. Geneva, Switzerland: IPCC, Switzerland, 2019.

[14] D. Maniatis *et al.*, "Toward a More Representative Monitoring of Land-Use and Land-Cover Dynamics : The Use of a Sample-Based Assessment through Augmented Visual Interpretation Using Open Foris Collect Earth," 2021.

[15] MoCC, "The Republic of Vanuatu Third National Communication." UNFCCC, 2020.

[16] P. Olofsson, G. M. Foody, M. Herold, S. V. Stehman, C. E. Woodcock, and M. A. Wulder, "Good practices for estimating area and assessing accuracy of land change," *Remote Sens. Environ.*, vol. 148, pp. 42–57, 2014.

[17] E. L. Bullock, C. E. Woodcock, and P. Olofsson, "Monitoring tropical forest degradation using spectral unmixing and Landsat time series analysis," *Remote Sens. Environ.*, vol. 238, p. 110968, Mar. 2020, doi: 10.1016/J.RSE.2018.11.011.

[18] S. Martínez and D. Mollicone, "From Land Cover to Land Use: A Methodology to Assess Land Use from Remote Sensing Data," *Remote Sens. 2012 Vol 4 Pages 1024-1045*, vol. 4, no. 4, pp. 1024–1045, Apr. 2012, doi: 10.3390/RS4041024.

[19] J. Chave *et al.*, "Improved allometric models to estimate the aboveground biomass of tropical trees," *Glob. Change Biol.*, vol. 20, no. 10, pp. 3177–3190, Oct. 2014, doi: 10.1111/gcb.12629.

[20] SPC/GIZ, "Regional REDD+ Project – Forest Conservation in the Pacific Island Countries.," 2019. https://reddpluspacific.org/ (accessed Mar. 03, 2022).

[21] IPCC, *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Institute for Global Environmental Strategies (IGES) for the IPCC, 2003.

[22] P. Olofsson, G. M. Foody, M. Herold, S. V. Stehman, C. E. Woodcock, and M. A. Wulder, "Good practices for estimating area and assessing accuracy of land change," *Remote Sens. Environ.*, vol. 148, pp. 42–57, 2014, doi: 10.1016/j.rse.2014.02.015.

[23] GFW, "How Tree Cover Loss Data Has Changed Over Time," 2021. https://www.globalforestwatch.org/blog/data-and-research/tree-cover-loss-satellite-data-trend-analysis/ (accessed Apr. 27, 2022).

ANNEX 1: Details of Biomass Pools

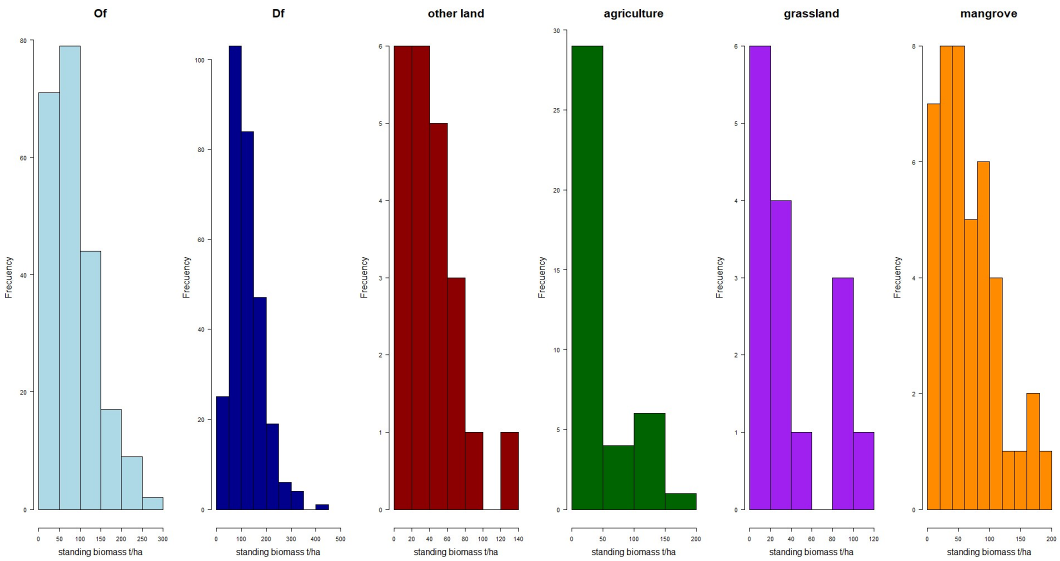
Note: BGB calculated from AGB using R:S ratios are not reported here.

Land cover class	Biomass (tdm/ha)	3294 Stdev	N° plots	SE	Source/comment	Land cover class
Dense Forest	AGB	121.06	± 62.8	289	± 3.7	NFI
Open Forest	AGB	86.14	± 55.5	222	± 3.7	NFI
Cropland	AGB	10.00	± 3.8	20	± 0.8	IPCC
Grassland	AGB	13.19	± 4.9	20	± 1.1	IPCC
Settlements	AGB	14.84	± 5.6	20	± 3.2	MoEF, 2018
Other	AGB	34.28	± 12.9	20	± 2.9	MoEF, 2018
Dense Forest	SDW	4.59	± 68.2	289	± 4.0	NFI
Open Forest	SDW	3.22	± 130.0	222	± 8.7	NFI
Cropland	SDW	-	-	-	-	n.a.
Grassland	SDW	-	-	-	-	n.a.
Settlements	SDW	-	-	-	-	n.a.
Other	SDW	-	-	-	-	n.a.
Dense Forest	AGB-Stumps	0.65	± 2.0	289	0.1	NFI
Open Forest	AGB-Stumps	0.22	± 1.5	222	0.1	NFI
Cropland	AGB-Stumps	-	-	-	-	n.a.
Grassland	AGB-Stumps	-	-	-	-	n.a.
Settlements	AGB-Stumps	-	-	-	-	n.a.
Other	AGB-Stumps	-	-	-	-	n.a.
Dense Forest	LDW	15.79	± 22.0	176	1.7	NFI
Open Forest	LDW	11.10	± 25.7	109	2.5	NFI
Cropland	LDW	-	-	-	-	n.a.
Grassland	LDW	-	-	-	-	n.a.
Settlements	LDW	-	-	-	-	n.a.
Other	LDW	-	-	-	-	n.a.
Dense Forest	Litter	5.01	± 5.1	289	0.3	NFI
Open Forest	Litter	4.19	± 4.8	222	0.3	NFI
Cropland	Litter	-	-	-	-	n.a.
Grassland	Litter	-	-	-	-	n.a.
Settlements	Litter	-	-	-	-	n.a.
Other	Litter	-	-	-	-	n.a.

ANNEX 2: Checks for Normal Distribution of Various Carbon Pools Sourced from the NFI Data

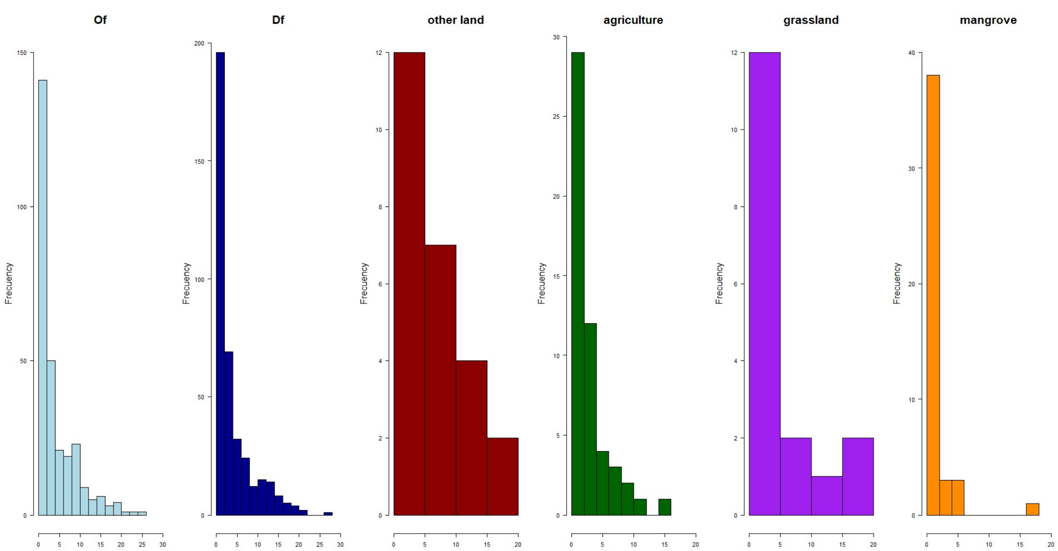
Standing biomass

	Of	Other land	Cropland	Df	Grassland	Mangrove
p-value	1.79e-10	**0.102**	7.084e-06	4.595e-10	0.0185	0.009504



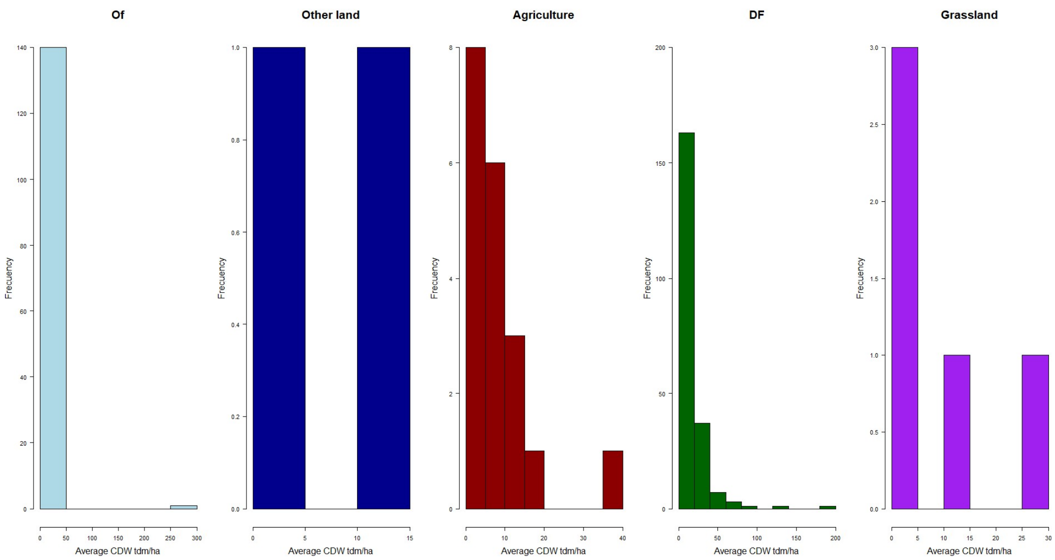
Litter

	Of	Other land	Cropland	Df	Grassland	Mangrove
p-value	2.2e-16	3.705e-12	3.052e-13	2.2e-16	3.357e-07	1.795e-12



Lying dead wood

	Of	Other land	Cropland	Df	Grassland
p-value	2.2e-16	Sample number to low (<3)	0.0001022	2.2e-16	0.1063



ANNEX 3: Details on QA/QC procedures

Table A 1: Code list of attributes for QA/QC.

ATTRIBUTE	DESCRIPTION
Cluster ID	A drop-down list of all clusters. No manual input is possible
Province and Island	Province and Island are preselected depending on the location of the cluster
Sample Plot Number	Possible choices 1-4. No additional plot or number can be added.
Accessibility	A selection list of possible attributes
Vegetation Type	A selection list of possible attributes, on 3 levels
Plot Partial	A selection list of possible attributes
Canopy Cover	A selection list of possible attributes
Ground cover type and coverage	A selection list of possible attributes
Disturbance	A selection list of possible attributes
Regeneration: Species	Species are selected from a drop-down list. Manual input of information is avoided
Tree category	A selection list of possible attributes
Tree: Species	Species are selected from a drop-down list. Manual input of information is avoided
Damage	A selection list of possible attributes
Use	A selection list of possible attributes
Use Type	A selection list of possible attributes
Decay class	A selection list of possible attributes
Litter: Presence	A selection list of possible attributes
Attribute	Description
Cluster ID	A drop-down list of all clusters. No manual input is possible
Province and Island	Province and Island are preselected depending on the location of the cluster
Sample Plot Number	Possible choices 1-4. No additional plot or number can be added.
Accessibility	A selection list of possible attributes
Vegetation Type	A selection list of possible attributes, on 3 levels

Plot Partial	A selection list of possible attributes
Canopy Cover	A selection list of possible attributes
Ground cover type and coverage	A selection list of possible attributes
Disturbance	A selection list of possible attributes
Regeneration: Species	Species are selected from a drop-down list. Manual input of information is avoided
Tree category	A selection list of possible attributes
Tree: Species	Species are selected from a drop-down list. Manual input of information is avoided
Damage	A selection list of possible attributes
Use	A selection list of possible attributes
Use Type	A selection list of possible attributes
Decay class	A selection list of possible attributes
Litter: Presence	A selection list of possible attributes

Table A 2: List of eligible NFI attributes for QA/QC.

ATTRIBUTE	DESCRIPTION	MESSAGE
All obligatory fields	Check if field is empty	Error message: (red flag)
Distance	Check: Distance < 12m	Error message: (red flag) the maximum distance of the measured trees from the plot center is 12m. Please check the distance and adjust the value.
DBH	Min set to 5cm	Error message: (red flag) Smallest diameter to be measured is 5cm. Please revise the value
	If distance >= 3m and DBH > 10cm	Error message: (red flag) the DBH in this size belongs to the first circle (r=3m) please check the values of DBH and distance
	If distance >= 6m and DBH > 20cm	Error message: the DBH in this belongs to the second circle (r=6cm), please check the value of distance or DBH
	Check if DBH is larger than 100cm	Warning message: (orange flag) Please check the values of the DBH, possibly you have missed a comma.