Establishment of a Reference Level (FRL) for forest land and development of a System for Monitoring, Reporting and Verifying (MRV) carbon emission reductions from forests in FIJI

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Methodology Development for FRL

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1 Abbreviations

AD	Activity data
AGB	Above-ground biomass
AI	Aridity Index
A.s.l.	Above sea level (m)
BGB	Below-ground biomass
CO_2e	Carbon dioxide equivalents
COP	Conference of the Parties to the UNFCCC
E	Environmental stress factor
EF	Emission factor
FAO	Food and Agriculture Organization of the United Nations
FCPF	Forest Carbon Partnership Facility of thehe World Bank
FHCL	Fiji Hardwood Corporation Limited
FPL	Fiji Pine Limited
FREL/FRL	Forest Reference Emission Level/Forest Reference Level
GFOI	Global Forest Observation Initiative
ha	Hectare(s)
IPCC	Intergovernmental Panel on Climate Change
LDF	Logging damage factor
LIF	Logging infrastructure factor
MC	Monte Carlo
Mg	Megagram
NFI	National Forest Inventory
PSP	Permanent Sample Plot
R	Root to shoot ratio
REDD+	Reducing Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries

SRTM	Shuttle Radar Topography Mission
TB	Total biomass
TC	Total carbon
TEF	Total (timber) emission factor
UNFCCC	Unied Nations Framework Convention on Climate change
WD	Wood density

CONTENT

2 Background

2.1 Aim

The goal of the Forest Reference Level (FRL) construction for Fiji is to estimate net historical forest-related emissions or removals for the period 2006 to 2016. The FRL will serve as a baseline against which future forest-related emissions or removals will be compared. For the FRL, the 17th session of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) (Decision 12/CP.17) requests countries to express emissions in metric tonnes of carbon dioxide equivalent (tCO_2e) per year. In this document, we propose a set of methodological approaches that we recommend as tools to estimate historical forest-related emissions in Fiji. To ensure consistency among historical, current and future estimates of emissions, the methodology proposed in this document is linked directly to the choice of methods that may be considered for future assessments. However, UNFCCC (Decision 12/CP.17, par. 10) “stresses the usefulness of adopting a stepwise approach, enabling countries to improve their FREL/FRL[1] over time by incorporating better data [and] improved methodology […]” (FAO, 2015a).

2.2 Scope and scale

2.2.1 REDD+ activities

The following three REDD+ activities will be included in Fiji’s FRL**,** as outlined in Fiji’s National REDD+ Policy [MPI, 2011] and the Emission Reductions Programme Idea Note [ER-PIN, 2016]:

a. reducing emissions from deforestation;
b. reducing emissions from forest degradation; and
c. enhancement of forest carbon stocks via afforestation and reforestation.

For Fiji’s FRL, these three activities translate to the following sources and sinks of Greenhouse Gases (GHGs): a) emissions from deforestation, b) emissions from forest degradation, and c) removals from afforestation and reforestation.

2.2.2 Pools

Of the five forest carbon pools identified by IPCC (2003a, 2006), above-ground biomass (AGB) and below-ground biomass (BGB) will be included in Fiji’s FRL construction. As of today, the contribution of the different carbon pools to total forest related emissions or removals is unknown in Fiji and, hence, no informed statement about their significance can be made. The decision which pools to include was guided by FCPF’s REDD+ Decision Support Toolbox (FCPF-DST), expert judgements, data availability and implications for future emission reduction estimates.

As significant pools, FCPF-DST identified (i) AGB, (ii) BGB and (iii) Soil Organic Carbon (SOC). For Fiji, no data are available for litter and dead wood in FCPF-DST. SOC is excluded from

[1] Although the UNFCCC did not explicitly specify the difference between a Forest Reference Emission Level (FREL) and an Forest Reference Level (FRL), a common understanding is that the FRL includes both, activities that reduce emissions and increase removals, while an FREL only includes activities that reduce emissions.

the FRL mainly for two reasons. Firstly, no national estimates of SOC stocks are available in Fiji.Secondly, knowledge on conversions of IPCC land-use categories (e.g., Forest Land to Grassland, Forest Land to Cropland, or Grassland to Forest Land) are required to estimate emissions/removals in SOC after land-use conversion. These data are currently not available in Fiji, because only conversions from Forest Land to Non-Forest Land and vice versa aree mapped for the FRL. IPCC [2003b] and IPCC [2006] do not provide default Emission Factors (EFs) for the conversion from Forest Land to Non-Forest Land, as the latter is not considered an IPCC land-use category. FCPF [2016, Indicator 4.2.ii] stipulates that “Carbon pools [...] may be excluded if: The ER Program can demonstrate that excluding such Carbon Pools [...] would underestimate total emission reductions”. By excluding SOC, future potential emission reductions will be underestimated.

Litter and Dead Wood are considered insignificant. Excluding Litter and Dead Wood will cause an underestimation of future emission reductions.

Table 1 Justification for the inclusion and exclusion of carbon pools.

Pool	Included	Justification
AGB	Yes	AGB is included in the FRL.
BGB	Yes	BGB is included in the FRL.
SOC	No	SOC is not included in the FRL. The exlusion of SOC will cause an underestimate of future emission reductions.
Litter	No	Litter is not included in the FRL. The exlusion of Litter will cause an underestimate of future emission reductions.
Dead Wood	No	Dead Wood is not included in the FRL. Excluding Dead Wood will cause an underestimate of future emission reductions.

2.2.3 Gases

The Agriculture, Forestry and Other Land Use (AFOLU) sector cover mainly three types of GHGs, namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (IPCC, 2006). Emissions of N_2O may be caused by biomass burning or any forest management practice that increases the availability of inorganic nitrogen in soils. However, unless lands have had a heavy application of nitrogen fertilizer, forest-related emissions of N_2O do not usually represent a key category (GFOI, 2016).

Similar to N_2O, CH_4 is released to the atmosphere when biomass is burned. In Fiji, man-made and wild fires are not uncommon (Trines, 2012), but national records on the cause, extent, and intensity are currently not available. The Burned Area Products from the Moderate-resolution Imaging Spectroradiometer (MODIS) was used to assess where burned areas were located between 2006 and 2016. An overlay of the forest cover maps of 2006 and 2012 produced by the Geoscience Division of the Pacific Community (SPC-GSD) and the MODIS Burned Area Products revealed that most of the burned areas were recorded in non-forested areas, mostly in grasslands. Fires that spread into forested areas were mostly located in pine plantations. AGB and BGB in pine stands are usually only significantly affected by fires if they are young (e.g., have been planted recently). However, these stands store only small amounts of carbon. Because of the lack of data on CH_4 and the supposedly minor contribution of non-CO_2 emissions to total emissions, only CO_2 will be considered during FRL construction.

Table 2 Justification for the inclusion and exclusion of GHG gases.

Gas	Included	Justification
CO_2	Yes	Carbon dioxide (CO_2) is inlcuded in the FRL.
CH_4	No	Methane (CH_4) is not included in the FRL. Burning of biomass in forests is considered negligible as man-made fires rarely significantly affect above- and below-ground biomass. Exclusion of CH 4 will cause an underestimation of future emission reductions.
N_2O	No	Nitrous oxide (N_2O) is not included in the FRL as forest management practices currently employed do not include heavy application of nitrogen fertilizer. Exclusion of N_2O will cause an underestimation of future emission reductions.

2.2.4 Scale

The FRL accounting area (i.e., the area for which the FRL is established) is subnational, including Fiji's three largest islands: Viti Levu, Vanua Levu and Taveuni. The accounting area covers about 89% of Fiji's forest area. A map of the FRL accounting area is shown in Figure 1.

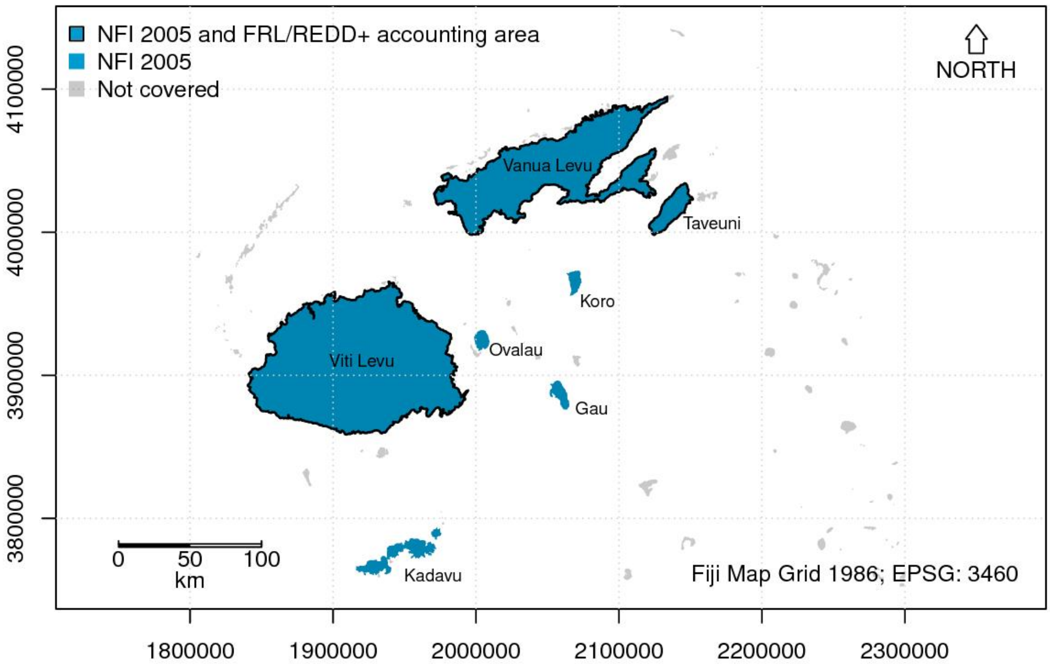

Figure 1 Map of Fiji. In blue: areas covered by the National Forest Inventory (NFI) 2005; blue with black outline: areas included for the Forest Reference Level (FRL) construction and the NFI 2005.

2.3 Definitions of forest, deforestation and forest degradation

2.3.1 Forest definition

The term 'forest' has not yet been formally defined in Fiji. For its national REDD+Policy (MPI, 2011), Fiji adopted the forest definition provided in FAO (2006):

"Land spanning more than 0.5 hectares with trees higher than five metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agriculture or urban use. Forest is determined both by the presence of trees and the absence of other predominant land uses. Areas under reforestation that have not yet reached but are expected to reach a canopy cover of 10 percent and a tree height of five metres are included, as are temporarily unstocked areas, resulting from human intervention or natural causes, which are expected to regenerate. Includes: areas with bamboo and palms, provided that height and canopy cover criteria are met; forest roads, fire breaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of scientific, historical, cultural or spiritual interest; windbreaks, shelterbelts and corridors of trees with an area of more than 0.5 hectares and width of more than 20 metres; plantations primarily used for forestry or protected purposes [...]. Excludes tree stands in agricultural production systems, for example in fruit plantations and agroforestry systems. The term also excludes trees in urban parks and gardens" (MPI, 2011).

2.3.2 Definition of classes of forests: deforestation, forest degradation, forestation, plantation and forest enhancement

For Fiji's FRL, the IPCC land-use category 'Forest Land' was disaggregated into two sub-categories ('Natural Forest' and 'Forest Plantation'). Each sub-category holds two forest strata: the sub-category 'Natural Forest' contains the strata 'Lowland forest' and 'Upland forest' and the sub-category 'Forest Plantation' contains the strata 'Softwood plantation' and 'Hardwood plantation' (Table 23).

The boundary between 'Lowland forest' and 'Upland forest' was drawn at 600 m above sea level (a.s.l.). 'Lowland forest' is located below 600 m a.s.l. and 'Upland forest' equal or above 600 m a.s.l. This threshold value was set based on findings of Mueller-Dombois & Fosberg [1998], who identified structural and floristical changes below and above the threshold. A preliminary analysis of the NFI 2006 data revealed significant differences in average carbon stocks [t ha^{-1}] between the two strata.

Mangrove forests are not included in the FRL. As of today, no national estimates of carbon stocks in mangrove forests are available in Fiji. For mangrove only Tier 1 methods could, therefore, be employed (i.e., default carbon stocks ha^{-1}), which may not be sufficient to meet FCPF's Methodology Framework (MF) requirements [FCPF, 2016]. A test inventory was recently conducted in Fiji's mangrove forests but the analysis of the data has not yet been finalized. Moreover, the primary purpose of conducting the test inventory was to assess how to efficiently set up an inventory within Fiji's mangrove forests. Once estimates of carbon stocks and associated Emission Factors (EFs) are available, mangrove may be included in an updated FRL.

The strata 'Softwood plantations' and 'Hardwood plantations' within the sub-category 'Forest Plantations' cover the areas leased by Fiji Pine Limited (FPL) and Fiji Hardwood Corporation Limited (FHCL), respectively. Softwood plantations are almost exclusively stocked with pine trees (*Pinus* [*Pinus*] *caribaea* Morelet). Hardwood plantations are mostly stocked with broadleaf mahogany (*Swietenia macrophylla* King). The sub-category 'Forest Plantations' does not include areas outside the plantation lease areas of FP and FHCL that are planted with e.g., pine or mahogany. These planted areas belong to the sub-category 'Natural Forest'. Hence, land that is classified as 'Natural Forest' cannot be converted to 'Forest Plantation' and vice versa. This distinction was made because it was not possible to distinguish between natural (native) forests and planted forests using the available remotely sensed data. However, the boundaries of the plantation lease areas could be clearly demarcated (i.e., polygon vector files of the lease areas are available). Note that the sub-category 'Natural Forest' should not be confused with "native" or "primary" forest as the sub-category "Natural Forest" includes forests that evolve from natural regeneration (of native species), as well as areas planted with introduced species.

The stratification of forests used for the FRL differs from the one given in Fiji's Country Report to FAO's Global Forest Resources Assessment (FRA) [FRA-Fiji, 2015]. The stratification provided in the FRA is based on forest cover maps produced by the Geoscience Division of the Pacific Community (SPC-GSD). To differentiate between closed and open natural forest unsupervised classification techniques were used. However, no rigorous accuracy assessment [Olofsson et al., 2014] has been conducted on these maps, and their quality remains unknown. For the FRL, the available remotely-sensed data did not allow to reliably distinguish between e.g., closed and open forest.

Table 3 IPCC land-use categories, sub-categories and forest strata used for Fiji's FRL.

IPCC category	Sub-category	Stratum	Description
Forest Land	Natural Forest	Lowland forest	The stratum 'Lowland forest' includes all areas classified as forest that are located <600 m a.s.l. It includes primary (native) forest, human modified forests as well as areas planted with native or introduced tree species. It does not include forest in plantation lease areas and areas classified as mangrove forest.
		Upland forest	The stratum 'Upland forest' includes all areas classified as forest that are located ≥600 m a.s.l. It includes primary (native) forest, human modified forests as well as areas planted with native or introduced tree species. It does not include forest in plantation lease areas and areas classified as mangrove forest.
	Forest Plantation	Softwood plantation	The stratum `Softwood plantation' includes all areas leased by Fiji Pine Limited (FPL) between 2006 and 2016. The boundary of the lease area of FP is available as a vector (polygon) file. Areas not currently stocked with trees (crown cover percent is zero) but which are situated within FP's lease area are

			classified as forest
		Hardwood plantation	The stratum `Hardwood plantation' includes all areas leased by Fiji Hardwood Corporation Limited (FHCL) between 2006 and 2016. The boundary of the lease area of FHCL is available as a vector (polygon) file. Areas not currently stocked with trees (crown cover percent is zero) but which are situated within FHCL's lease area are classified as forest.
Non-Forest Land		Non-forest	The land-use category `Non-Forest Land' includes all areas not classified as `Forest Land'. For the FRL, areas classified as mangrove forest are included in the land-use category `Non-Forest Land'. Note that `Non-Forest Land' is not an IPCC land-use category. For the FRL, the land-use category `Non-Forest Land' includes all IPCC land-use categories, i.e., `Grassland', `Cropland', `Wetlands', `Settlements' and `Other Land', except the category `Forest Land'.

The UNFCCC defined deforestation (Decision 16/CMP.1) as “the direct, human-induced conversion of forested land to non-forested land”. For the FRL, deforestation was defined as the conversion of land classified as ‘Natural Forest’ to land classified as non-forest. Deforestation can only occur in the sub-category ‘Natural Forest’ and cannot occur in the sub-category ‘Forest Plantation’. Areas within the plantation lease area that are not currently stocked with trees are still considered as forest (i.e., “temporarily unstocked” as defined in Fiji’s forest definition). Hence, areas belonging to the sub-category ‘Forest Plantation’ that are cleared, i.e., all trees are removed, will not be considered as deforestation.

The IPCC report on “Definitions and Methodological Options to Inventory Emissions from Direct Human-Induced Degradation of Forests and Devegetation of Other Vegetation Types” [IPCC, 2003a] suggests the following characterization of the term “forest degradation”: “A direct, human-induced, long-term loss (persisting for X years or more) or at least Y % of forest carbon stocks [and forest values] since time T and not qualifying as deforestation.” The term “forest degradation” is not defined in Fiji and no quantitative threshold values are in use that allow to assess forest degradation either in the field or by remotely sensed data. For the FRL, emissions from forest degradation are estimated using proxy data, namely logging statistics. No data on forest degradation caused by wood fuel collection are available in Fiji and the FCPF-DST. However, emissions from wood fuel are considered insignificant (ER-PIN, 2016).

3 Methodological framework to estimate emissions by sources and removals by sinks

3.1 General approach

For the FRL construction we consider four sources of emissions/removals: (i) emissions from deforestation in natural forests, (ii) emissions from logging in natural forests (i.e., degradation), (iii) emissions and removals in forest plantations, and (iv) removals from afforestation in areas that have not been forested at the beginning of the reference period (i.e., 2006). These four sources link to the three REDD+ activities reducing emissions from deforestation, reducing emissions from forest degradation and enhancement of carbon stocks. For the FRL (i) to (iv) will be combined and net emissions (or removals) will be estimated, i.e.,

Net emissions/removals = Emissions (from (i), (ii) and (iii)} – Removals {from (iii) and (iv)}.

As described in the previous section deforestation occurs only in natural forest. Afforestation occurs in areas that were not forested in 2006 and are not located in areas designated as plantation areas, i.e., lease areas of FPL and FHCL. To estimate emissions from deforestation the gain-loss method will be applied (see Section 3.3.1). For the gain-loss method the average carbon stock per hectare needs to be estimated. This estimate is called the emission factor (EF). In order to estimate emissions from deforestation, the carbon stock estimate is multiplied by the area of forest loss (in hectares) during the reference period 2006 -2016. Removals from afforestation are estimated in a similar way. Net emissions are estimated as shown above. To estimate areas of forest loss and gain, the Geoscience Division of the Pacific Communities (SPC-GSD), located in Suva, Fiji Islands produces a forest map that depicts areas of forest change between 2006-2012 and 2012-2016. The change map is based on an overlay of a forest cover map from 2006 to 2012 for the first period and from 2012 to 2016 for the second period.

Plantation areas and areas that were logged will be excluded from mapping, because areas harvested will be taken from logging statistics of FPL and FHCL. For the estimation of emissions/removals from deforestation/afforestation a single estimate for the entire reference period will be available. This estimate will be annualized by dividing total emissions by (2012 - 2006) = 6 years and (2016 – 2012) = 5 years. *The forest change maps are still not available to the consultancy team!*

Emissions from logging in natural forest (i.e., forest degradation) are estimated using national logging statistics. These statistics provide annual data on the volume logged and the area where the logging took place within the reference period. Logged volumes will be converted to CO_2e and will be treated as committed (i.e., direct) emissions, even if the carbon is stored in wood products and not directly emitted to the atmosphere. Emissions from logging do not only result from the extracted timber itself but also from logging residues (e.g., tree stumps and crowns left as logging residiues in gap from felled tree in the forest), damage to nearby trees (i.e., incidental damage) and construction of logging infrastructure (e.g., log-landings or skid trails). To account for these additional sources of emissions, the carbon logged will be multiplied by a Logging Emission Factor (LEF). The LEF will be taken from a study that was conducted in Fiji (see Haas (2015)) and LEF estimates from other tropical countries. Emissions from logging in natural forests will be estimated on an annual basis, since logged volumes are recorded annually. *Data on logged volumes and areas harvested were provided by Divisional Forest Offices, but serious flaws in the data were detected and no updated data were provided to the consultancy team so far!*

Emissions and removals from plantations (pine and mahogany) will be estimated using data that are available at Fiji Pine Limited and Fiji Hardwood Corporation Limited. *These data are partly available to the consultancy team, but serious flaws in the data were detected and no updated data are yet available!* To estimate emissions from plantations, the volumes harvested per year will be converted to CO_2e, such that average annual emissions can be estimated. Removals will be estimated by multiplying the areas planted in a year, by estimates of growth extracted from yield functions that are available for FPL and FHCL. In a similar way, the removals from plantation areas that were neither harvested nor planted between 2006-2012 and 2012-2016 will be computed.

Figure 2 shows the three sources of forest-related emissions that are considered for the FRL construction in Fiji. For each of the three components the uncertainty attached to the emission estimate will be estimated using either readily available estimators (i.e., formulas), or, if the estimation procedures are more complex (e.g., Tier 2 and Tier 3), Monte Carlo (MC) simulations will be conducted. The final result of the FRL construction will be a single annualized CO_2e emission/removal estimate for the period 2006 to 2016, including an estimate of precision. Annual estimates of the two periods 2006-2012 and 2012-2016 will be combined by computing a weighted historical average. *These estimates can only be produced, if the (existing) data are made available to the consultancy team!*

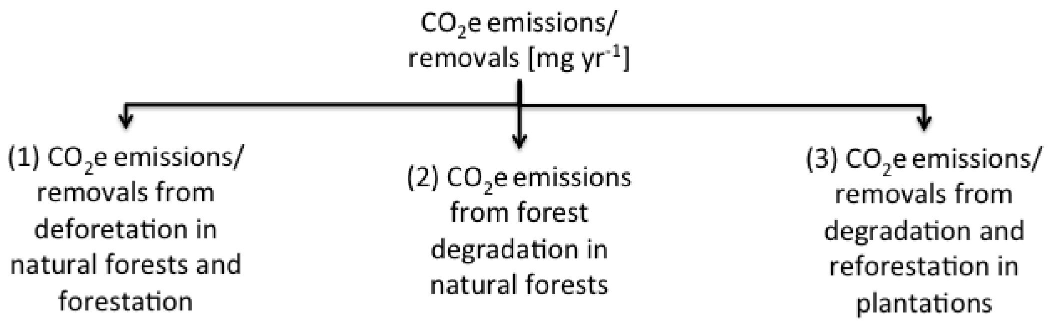

Figure 2 The figure shows the three sources of forest-related emissions that are considered for the FRL construction in Fiji. The three sources render different sets of data fort the assessment of Activity Data (AD) and Emission Factors (EFs) necessary (Table 4). For each of the three components the uncertainty attached to the emission estimate.

3.2 Data sources

Several sources of data and information are used for the FRL construction. A brief overview is provided in the following compilation:

NFI 2005	Data from Fiji's third National Forest Inventory (NFI) 2005. The NFI data are the primary source to estimate emission factors (EF) in Fiji's natural forests (excluding mangrove forests).
PSP	Data from Fiji's Permanent Sample Plot (PSP) program. Data from the first PSP round (2010) is used to derive diameter-height models, which are used as input to derive emission factors.
SRTM	Elevation (model) data from the Shuttle Radar Topography Mission. The SRTM data are used to derive emission factors for different elevation levels (domains/strata).

Aridity Index (AI)	A global raster map that is used to select default root:shoot ratios (R) to derive estimates of below-ground biomass (BGB). The raster is available on the web.
ESF	A global raster of the environmental stress factor (ESF). The ESF is used to predict above-ground biomass (AGB) of single trees as input to derive emission factors for natural forests. The ESF raster map is available on the web.
Wood Density Database	Database of estimates of wood specific gravity for tropical tree species. Used as input to predict single tree AGB.
Satellite imagery	Satellite data (mostly Landsat) to create forest cover and forest cover change maps and to obtain Activity Data (AD) for the reference period (including data procurement for the accuracy assessment, i.e., the reference or validation dataset).
Vector data	Georeferenced vector data, used to derive emissions from forest degradation in natural forests (excluding mangrove) and planted forests. The vector data are also used to exclude logged areas from deforestation mapping.
Logging statistics	National statistics of wood volumes removed from natural forests. Used to derive emissions from forest degradation in natural forests.
Plantation	Data from pine and mahogany plantations managed by Fiji Pine Limited and Fiji Hardwood Corporation Limited. The data are used to derive emissions from forest degradation and removals from reforestation in plantations.
Auxiliary information	Data and information from several (local) study reports, research articles and the IPCC guidance and guidelines documents [IPCC, 2003b, 2006].

3.3 Emissions from deforestation and removals from forestation

3.3.1 General approach

In its “Good Practice Guidance” (IPCC, 2003b) and “2006 Guidelines” (IPCC, 2006) the IPCC distinguishes between two methods to estimate GHG emissions and removals: the stock change method and the gain-loss method. For the stock change method (called the stock difference method in IPCC (2006)) net annual emissions are estimated from the difference in total carbon stocks at two points in time, divided by the number of intervening years. Carbon stocks are estimated from repeated field measurements from national forest inventories (NFIs); remotely sensed data may be used as auxiliary data to improve the efficiency of the estimation. For the gain-loss method net annual emissions are estimated as the sum of gains and losses in the different carbon pools. The gain-loss method requires the estimation of emission or removal factors (EF)[2] and activity data (AD). AD are data on the extent of human activity causing emissions and removals, and are often data on areas or areas of change (e.g., a change from Forest Land to another land use category, or change from Non-Forest Land to Forest Land in case of removals) (GFOI, 2016). EF are emissions or removals per unit activity. For the gain-loss method, total net carbon emissions or removals are estimated as the product of estimated AD and their associated EF estimates:

Net carbon emissions/removals = AD x EF

For the FRL construction in Fiji, the gain-loss method will be applied for the estimation of emissions from deforestation in natural forest (excluding mangrove forests). The data sources used for estimating emissions from deforestation/afforestation, forest degradation, and emissions/removals from degradation and reforestation in plantations are presented in Table 4.

Table 4: Data sources for estimating emissions from deforestation/afforestation, forest degradation, and emissions/removals from degradation and reforestation in plantations

Sources of CO_2e emissions/ removals	AD	EF	Uncertainty assessment
Deforestation	Remote sensing[1]	NFI 2005	Monte Carlo (MC)[5], Accuracy assessment
Afforestation	Remote sensing[1]	NFI 2005	MC, Accuracy assessment
Forest remaining forest	Remote sensing[1]	NFI 2005	MC, Accuracy assessment
Degradation	Logging areas[2]	Volume logged[3]	MC
Emissions/ removals from plantations	Plantation area[4]	Changes of per year growing stock[4]	MC

[1)] Excluding logging areas and plantation areas

[2)] obtained from Harvested Area Reporting (HAR)

[3)] obtained from Timber Revenue System (TRS) database

[4)] provided by Fiji Pine Ltd. and Fiji Hardwood Corporation Ltd.

[5)] Monte Carlo methods

[2] The acronym EF includes emissions as well as removals.

3.3.2 Emission factors

The primary source to derive emission factors for natural forest is data from Fiji's NFI 2005. For the NFI 2005, attributes of trees were recorded on in total n = 1023 fixed area cluster plots. Data collection started in 2006 and was finalized in late 2007. A stratified simple random sampling design was employed, where the strata were closed and open forest. The map that was used for stratification was derived by visual interpretation of Landsat imagery that was acquired between 2000 and 2002.

To derive emission factors from the NFI 2005 data several steps were necessary. First, the above-ground biomass of individual trees needed to be predicted. This is commonly done by applying allometric models that relate easy to measure tree attributes (e.g., diameter at breast height [DBH], species and total tree height) to the AGB of an individual tree. Up until now, no country-specific allometric models are currently available in Fiji that allow for a nation-wide application. Therefore, two candidate models were selected that have been published in Chave et al. (2014). Equation 7 in Chave et al. (2014) requires as input the DBH, the wood specific gravity and a so-called environmental stress factor. The DBH was measured during the NFI 2005. Wood densities were extracted from available literature resources and global databases (Zanne et al., 2009). The environmental stress factor E — which serves as a substitute for height measurements — is available in the form of a global raster map. As the geographic positions of NFI cluster plots were known, the value of E was extracted at each plot location and was attached to the trees located on the respective plot. The AGB was predicted for all trees recorded during the NFI 2005, using Chave et al.'s (2014) Euqation 7.

The second model, Equation 4 in Chave et al. (2014), requires the DBH, wood density and measured total tree height as input to predict the AGB of an individual tree. Total tree height was not measured during the NFI 2005, however. To predict the heights of trees, data from Fiji's Permanent Sample Plot (PSP) program was used. During the first round of the PSP program (2010), the DBH, species and height was measured on trees located on 86 fixed area sample plots. In total more than 9000 trees were recorded and for more than 5000 of them records of the DBH, species and tree height were available. These data were used to derive a diameter-height model, which was then applied to the NFI 2005 dataset. Once tree heights were predicted using the PSP height model, Equation 4 in Chave et al. (2014) was used to predict the AGB of all NFI trees.

When the AGB predictions of the two models were compared, large deviances were observed. Therefore, a third AGB model was considered. This "adjusted" allometric model was derived by refitting Chave et al. (2014)'s Equation 4 to a subset of the data Chave et al. (2014) used to derive the allometric model. The subset was chosen such that the diameter-height relationship was similar to the relationship found for the PSP data. The model was used to predict the AGB of all trees recorded during the NFI 2005. Although a pan-tropical dataset was used to derive the AGB model for Fiji, locally available data were used to adjust the model, and, hence, we consider this approach as being Tier 2 (see IPCC (2006))

After the AGB was predicted for individual trees, AGB was aggregated at the cluster plot level and expanded to per hectare values, i.e., n = 1023 predictions of AGB [t ha^{-1}] were available. These plot level predictions were used as input to compute estimates of below-ground biomass (BGB) at the plot level.

To derive BGB, default root:shoot ratios (R) found in IPCC(2006) were used. IPCC(2006) provide ratios for different ecological zones and Fiji falls entirely into the "Tropical rain forest" zone. However, with respect to rainfall, the mountainous topography in Fiji, combined with the southeast trade winds, produce a pronounced windward-leeward effect (ranging from about 3000 mm rainfall per year, or more at higher elevations, to about 1800 mm per year, or less in sheltered positions) (Mueller-Dombois & Fosberg, 1998). For a more detailed zoning, the following three zones were considered: "Tropical rain forest" (≤3 months dry during winter), "Tropical moist deciduous forest" (3-5 months dry during winter) and "Tropical mountain systems" (altitudes approximately > 1000 m with local variations). The decision which R to apply was guided by the aridity index (AI; Zomer et al., (2008)) and altitude at plot location. Plots located ≥ 600 m above sea level (a.s.l.) were classified as "Tropical mountain systems" (see Mueller-Dombois & Fosberg (1998; page 121)). To differentiate between tropical rain- and tropical moist deciduous forest (among plots that were located < 600 m a.s.l.), different thresholds of the AI were considered. Table 5 shows which R was used for the NFI 2005 plots.

Table 5 Root:shoot ratios (R) used to compute values of BGB = AGB _ R [t]. Adopted from Table 4.4 in IPCC [2006, Chapter 4].

Ecological zone	**Altitude [m]**	**AI**[3]	**AGB [t ha^{-1}]**	**R**[4]
Tropical rainforest	<600 m a.s.l.[5]	≥2		0.37
Tropical moist deciduous forest	<600 m a.s.l.	<2	≥125	0.24
		<2	<125	0.20
Tropical mountain systems	≥600 m a.s.l.			0.27

Once AGB and BGB were available at the plot level, total biomass (TB) was predicted for each NFI 2005 cluster plot as TB = AGB + BGB. Afterwards, TB was converted to total carbon (TC) and TC = TB x 0.47 was converted to carbon dioxide equivalents (CO_2e = TC x 44/12). Table 6 shows the conversion factors which were applied. All estimates were based on the adjusted allometric model. For FRL construction the adjusted model will be chosen, because we assumed, that this model lead to the supposedly smallest bias (i.e, the smallest systematic difference between the predicted and unknown "true" AGB [Mg] of an individual tree). Moreover, using the adjusted model will reduce the risk of overestimating potential future emission reductions.

Table 6 Conversion factors used to estimate below-ground biomass, total biomass, total carbon and carbon dioxide.

Name	Abbreviation	Unit	Conversion
Above-ground biomass	AGB	t ha^{-1}	
Below-ground biomass	BGB	t ha^{-1}	BGB = AGB x R
Total biomass	TB	t ha^{-1}	TB = AGB + BGB

[3] AI = Aridity Index

[4] R = root to shoot ratio

[5] A.s.l. = above sea level

Total carbon	TC	t ha^{-1}	TC = TB x 0.47
Carbon dioxide equivalent	CO_2e	t ha^{-1}	CO_2e = TC x 44/12 = TC x 3.667

Estimators that are commonly applied for stratified simple random sampling designs were used to predict average CO_2e [t ha^{-1}] for the two strata “closed forest” and “open forest” and several domains (i.e., subpopulations that may cut across strata). The estimators are found in Särndal et al. (1992). The analysis revealed that no significant differences in CO_2e [t ha^{-1}] were found between closed and open forest, most likely because the differentiation of closed and open forest using unsupervised classification was poor.

Estimates were computed by only considering those plots that fell into the FRL accounting. Average CO_2e [t ha^{-1}] was also estimated for different elevation levels: lowland (plots below 600 m above sea level) and upland (plots equal or above 600 m above sea level). CO_2e [t ha^{-1}] differed significantly between the two domains. We, therefore, recommend applying different emission factors for the two domains “Lowland forest” and “Upland forest”. A finer “stratification” (or breakdown into domains) may not be favorable from a statistical point of view, because this splitting may increase variances of CO_2e [t ha^{-1}] estimates within the domains.

Variances of emission factor estimates were computed in two different ways. First, variances were estimated assuming that the plot level CO_2e [t ha^{-1}] predictions are free of error (i.e., ignoring the uncertainty that results from using an allometric model). Closed form estimators (i.e., formulas) exist, that can be applied to estimate the variance of population, strata and domain means and totals. To account for the uncertainty in the adjusted allometric model, a Monte Carlo (MC) simulation will be conducted in which random errors are added to different components of the model. For the simulation, the following random errors will be added:

- Random error in wood density estimates (error randomly drawn from a Normal distribution with mean zero and a standard deviation that is estimated from the variability in wood density estimates).
- Random error in predicted heights (error randomly drawn from a Normal distribution defined by the distribution of residuals of the height model).
- Error from the refitted allometric model (error from a Normal distribution defined by the residual distribution of the refitted model).

These errors will be added to individual tree level AGB predictions. Afterwards plot level AGB will be aggregated (as described above). In total 10,000 runs will be conducted (i.e., AGB is predicted for each plot 10,000 times). In a next step, a random error is added to the root:shoot ration R. Parameters for the error distribution will be taken from Table 4.4 in IPCC (2006). To account for sampling error, bootstrap samples will be taken from simulated plot data [CO_2e t ha^{-1}]. The final estimation error will be computed by taking the standard deviation of 10,000 bootstrap estimates of the target parameter CO_2e [t ha^{-1}].

3.3.3 Activity data

Land cover change information provides the basis for estimating emissions and removals from human activity (activity data - AD). The procurement and analysis of AD should follow IPCC good practice guidelines that advocate neither over- nor under-estimating GHG emissions or removals and reducing uncertainties as far as is practicable (IPCC 2006, GFOI

2003, 2016). To estimate accurate and consistent AD for Fiji, a forest area change assessment and an accuracy assessment have been carried out.

The following 4 steps (Figure 3) best describe the overall methodology adopted for accuracy assessment of forest change. This approach is based on IPCC good practice guidelines and is recommended by Olofsson et al. (2014) and the Global Forest Observation Initiative (GFOI, 2016; section 5.1.5.).

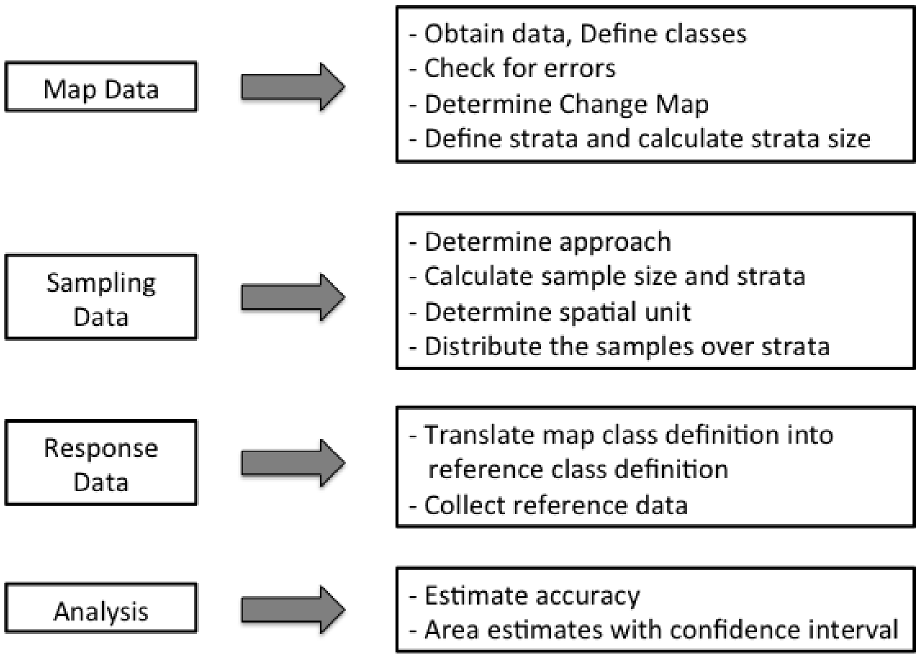

Figure 3 Methodology for forest change accuracy assessment.

Activity data used for FRL construction for Fiji will be taken from a land cover change assessment conducted between the years 2006-2012 and 2012-2016. The focus of change assessment is primarily on changes between forest and non-forest categories including the strata Lowland and Upland forest. Landsat Thematic Mapper (TM) data downloaded from the United States Geological Survey (USGS) Global Visualization Viewer (GloVis) were used to obtain land cover data. In addition, geospatial information of the Fiji Ministry of Lands and Mineral Resources, Lands Department, river system and Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) with 30 m and 90 m resolutions were used as supplementary data. Land cover data for 2006, 2012 and 2016 as well as the change detection map have been prepared by the Pacific Community (SPC), Geoscience Division.

A specific problem for the South Pacific region is the limited availability of historical satellite data, which is partly due to persistent cloud cover, non-regular recording of satellite imagery due to the lack of receiving stations and inadequate data access infrastructure in the region. Therefore, the assessment of accuracy of forest change could not be done through comparing map data with greater quality reference data. Instead a sampling approach was applied that implemented an independent second image interpretation of Landsat TM data (i.e., assessing the accuracy of a map using independent reference data). The comparison of reference (i.e. independent interpretation) and map data (i.e. interpretation by SPC-Geoscience) allowed for bias-corrected area estimates with associated confidence intervals (GOFC-GOLD 2016).

3.3.3.1 Methodology for land cover interpretation

Map data refers to the input maps used for forest change assessment. Considering the requirement of historical data for FRL construction, a review of existing cloud-free satellite imagery for the years 2006, 2012 and 2016 was conducted. The following criteria were adopted based on expert consultation for selecting the appropriate satellite scenes for map source:

- Historical coverage,
- Wall-to-wall coverage,
- Cloud-free coverage,
- Derived from same sensor configuration,
- Consistent in scale and spatial extent,
- Proven accuracy measures, and
- Well accepted by the FRL team and REDD+ SC Fiji.

Landsat TM scenes were found that meet the above mentioned criteria. The data preparation included an atmospheric correction of the image data and a geometric correction with reference to the Lands Department river system. The corrected satellite imagery for 2006 and 2016 was embedded in a GIS, and two GIS backdrops were produced:

-True color composite (RGB: red, green, blue), see Figure 4
-False color composite (blue, green, near infrared), see Figure 5

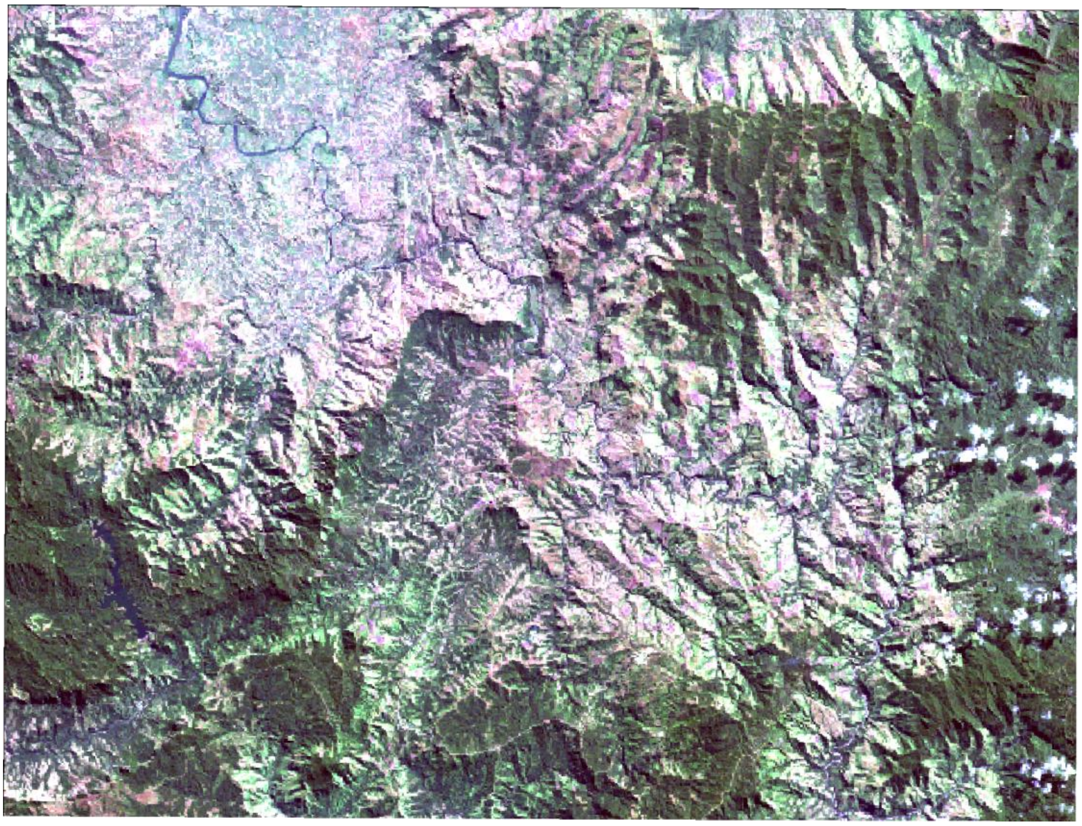

Figure 4 True color composite – close-up (RGB: red, green, blue).

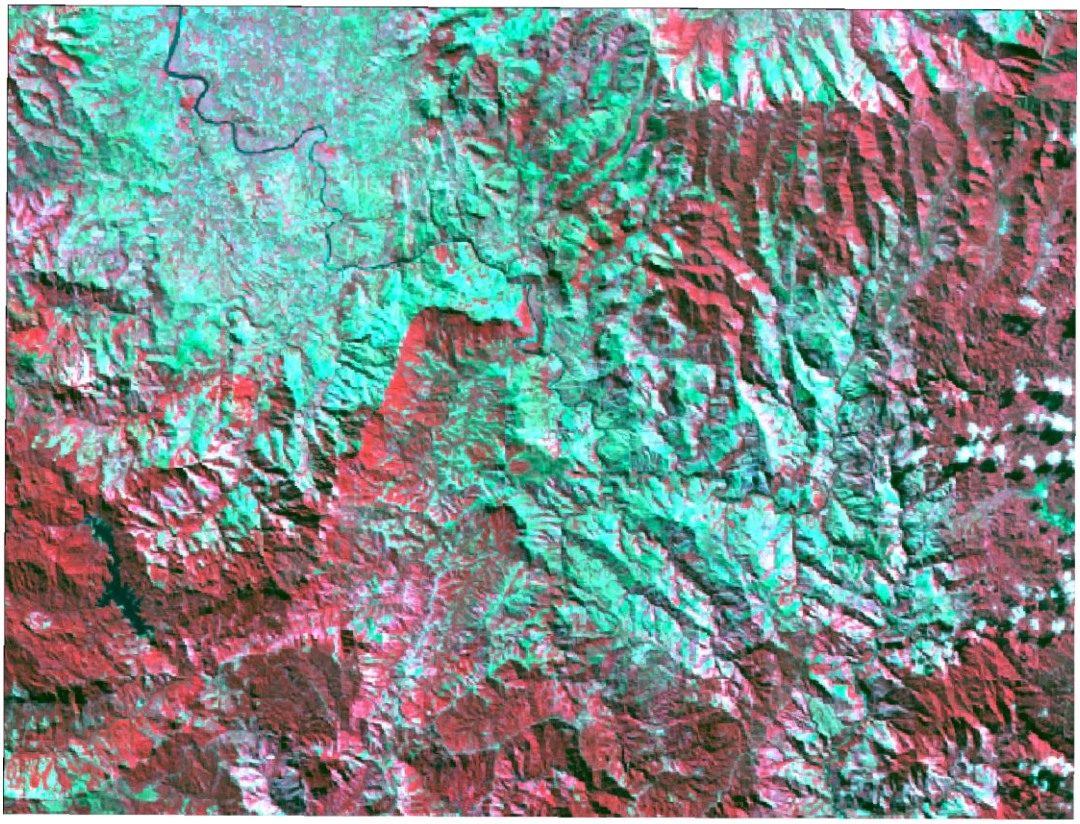

Figure 5 False color composite – close-up (blue, green, near infrared).

In 2007 forest polygons have been digitized from Landsat TM imagery that contain the boundaries between forest and non-forest areas. The GIS-data of 2006, 2012 and 2016 were overlaid with those polygons. Subsequently the 2007 polygons were adjusted for the 2006, 2012 and 2016 situation. The resulting forest boundaries for 2006, 2012 and 2016 were combined with auxiliary raster data (i.e. water, forest plantations) and converted to thematic raster maps. The classes assigned to each pixel follow the classification system shown in Table 7 Land cover classification.

Table 7 Land cover classification.

Class	Code
1	Forest
2	Mangrove
3	Pine plantation
4	Mahogany plantation
5	Coconut plantation
6	Water body
7	Non-forest

In order to be consistent with the definition of the REDD+ accounting area and the overall approaches to estimate (1) emissions in natural forests, (2) emission from logging in natural forests, and (3) emissions and removals from management of plantations; the forest area displayed in the 2006, 2012 and 2016 raster data had to be adjusted. Therefore, water bodies (class 6), plantation areas (classes 3 and 4), coconut plantations (class 5) and mangroves (class 2) were excluded. Plantation areas were excluded because, emission and removals will be estimated differently using data provided by FPL and FHCL.

Figure 6 summarizes the workflow for the land-use interpretation and subsequent land-use change assessment.

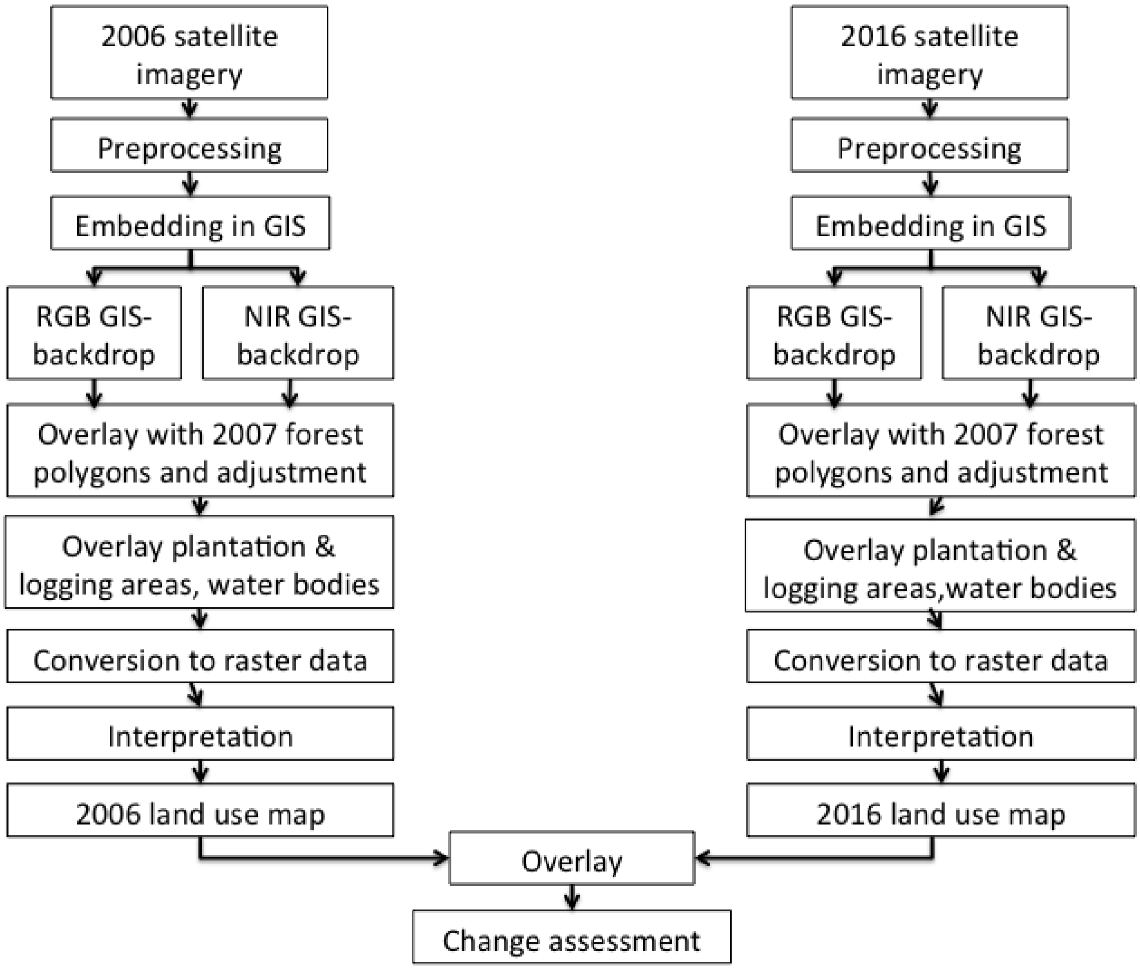

Figure 6 Workflow showing land-use interpretation and land-use change assessment.

3.3.3.2 Land-use change assessment

In a final step, the resulting raster data for 2006, 2012 and 2016 are overlaid and six area change classes (i.e. forest remaining forest, land converted to Forest Land, Forest Land converted to non-forest Land for both strata Lowland and Upland forest) are calculated for each pixel (Figure 7). The raster data are cut into map sheets and the respective area changes are calculated. In addition, each pixel will be classified as being located over or below 600m a.s.l., utilizing the SRTM digital terrain model. The use of the biophysical factors (correlation between elevation and biomass/carbon density) as a basis for stratification of forest cover will increase the accuracy and precision of the measuring and monitoring forest carbon.

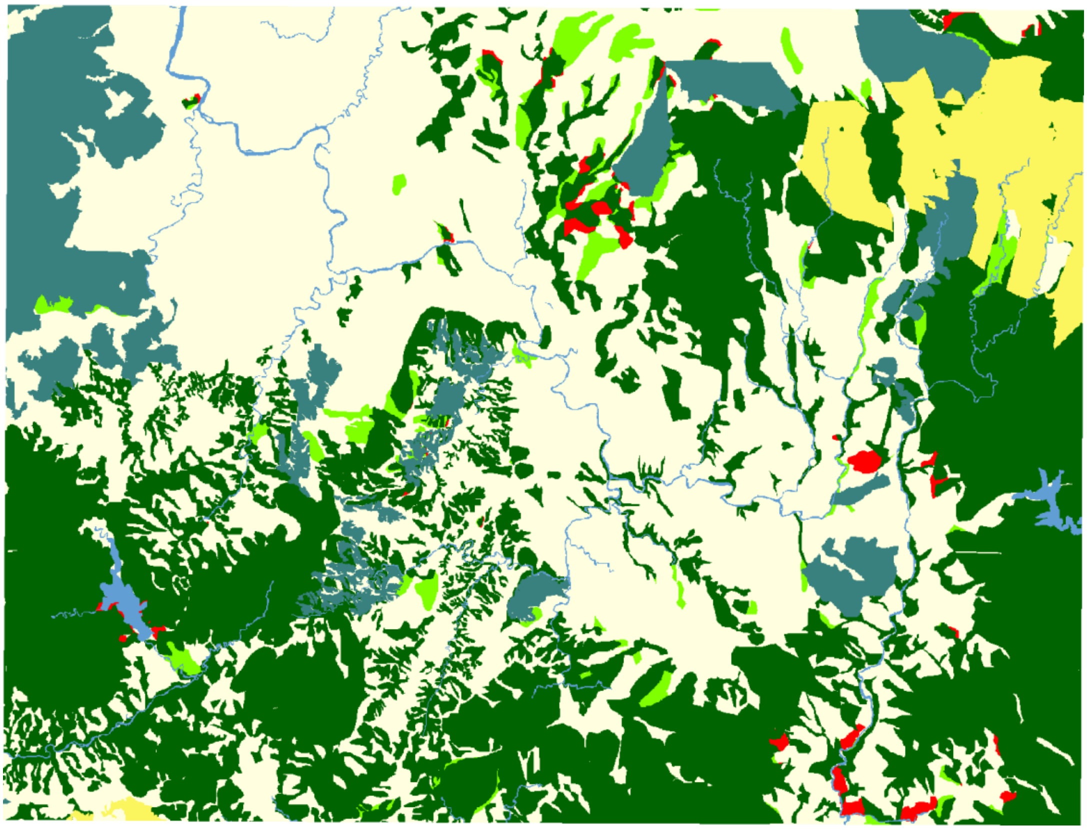

Figure 7 Land-use change map – green: forest remaining as forest, red: forest loss, light green: forest gain, blue: water bodies, white: non-forest remaining as non-forest.

The following statistics (Table 8) will be provided to show the distribution of change area and stable forest and non-forest areas across the REDD+ accounting area. See Chapter 0 for the respective estimation procedures.

Table 8 Forest area change across strata.

Strata	Forest loss area		Forest gain area		Stable forest area		Stable non-forest area	
	ha	%	ha	%	ha	%	ha	%
>600m a.s.l.								
≤600m a.s.l.								
Grand total								

3.3.3.3 Accuracy assessment[6]

An accuracy assessment of the land-cover change map using simple random sampling design will be conducted. A critical step in accuracy assessment is the selection of a suitable source for reference data. For 2006 no satellite imagery with higher resolution than the utilized Landsat TM data is available. The sample points of the NFI 2005 are not suitable as reference, as they are located in forest areas only and would thus introduce a considerable bias in the accuracy assessment. This holds especially true, as the NFI data include no in-situ information on non-forest areas, i.e. non-forest areas interpreted as forests cannot be detected. Therefore, Landsat TM data are to be used (as independent reference data) for verification and accuracy assessment. Thus, the same data source (i.e. Landsat TM) is used for interpretation and verification, which renders the conduction of the accuracy assessment (i.e., the collection of reference data) by an independent third body necessary.

Stratified random sampling will be chosen as it is a practical design that satisfies the basic accuracy assessment objectives for most of the desirable design criteria (Olofsson et al., 2014) and it helps the country to conform with the IPCC good practice principle of removing bias and reporting uncertainties transparently (GFOI, 2016). Within the strata the sampling points will be distributed by random. The number of sample plots is determined based on a standard sampling design method suggested by Olofsson, et al. (2014).

The accuracy assessment has two key objectives of the analysis: 1) accuracy assessment of the change classification, and 2) estimation of area of change. The error or confusion matrix (hereafter noted as the error matrix) plays a central role in meeting both the accuracy assessment and area estimation objectives (Olofsson et al., 2014; Congalton & Green, 2009). The error matrix is a simple cross-tabulation of the samples of classes interpreted and allocates the classification of the remotely sensed data against the reference data. Table 9 presents the error matrix to be derived. Error matrices will be constructed for both periods 2006-2012 and 2012-2016.

Table 9 Example of an error matrix for the first period.

2006-2012		Reference data					
		Forest loss	Forest gain	Stable forest	Stable non-forest	Total samples in map classes	Users's accuracy
Map data	Forest loss						
	Forest gain						
	Stable forest						
	Stable non-forest						

[6] The presentation follows Olofsson et al., 2014

Total reference samples per class						
Producer's accuracy						

From the error matrix the following accuracy parameters can be derived:

Overall accuracy:

$O = \sum_{j=1}^{q} p_{jj}$ ....(eq. 1)

User's accuracy of class *i* (i.e. the proportion of the area mapped as class *i* that has reference class *i*), U_i, or its complementary measure, commission error of class *i*,

$U_i = p_{ii}/p_i$ ....(eq. 2)

Commission error = 1-p_{ii}/p_i

Producer's accuracy of class *j* (the proportion of the area of reference class *j* that is mapped as class *j*), P_j, or its complementary measure omission error of class *j*

$P_j = p_{jj}/p_j$ ....(eq. 3)

Omission error of class *j*, 1 – p_{ii}/p_i

where

p_{ij} = proportion of area for the population that has map class *i* and reference class *j*, = N_{ij}/N

q = number of classes

N = total number of pixels

N_{ij} = number of pixels that has mapped class i and reference class *j*

As no full tally but a sample of pixels used as reference points is available, the proportions are obtained as sample estimates. Therefore, the values for p_{ii}, p_{jj} and p_i in equations 1 to 3 are to be replaced by the sample estimates $\hat{p}_{ii}$, $\hat{p}_{jj}$, and $\hat{p}_i$. For equal probability sampling designs (e.g., systematic sampling) and for stratified random sampling in which the strata correspond to the map classes,

$\hat{p}_{ij} = W_i \frac{n_{ij}}{n_{i.}}$ ....(eq. 4)

where W_i is the proportion of pixels mapped as class *i*, $W_i = n_k/n$.

The error matrix has to be constructed utilizing the estimated proportions. The sampling variability associated with the accuracy estimates is quantified by the respective sampling errors. Those are obtained for the estimated overall accuracy, $\hat{O}$, by

$\hat{V}(\hat{O}) = \sum_{i=1}^{q} \frac{W_i^2 \hat{U}_i(1-\hat{U}_i)}{n_i - 1}$ ....(eq. 5)

for the estimated users's accuracy for class *i*, $\widehat{U}_i$, by

$\hat{V}(\widehat{U}_i) = \frac{\hat{U}_i(1-\hat{U}_i)}{n_i - 1}$ ....(eq. 6)

and for the estimated producer's accuracy for class *j*, $\hat{P}_j$, by

$\hat{V}(\hat{P}_j) = \frac{1}{\hat{N}_{.j}^2} \left[\frac{N_{j.}^2 (1-\hat{P}_j)^2 \hat{U}_j (1-\hat{U}_j)}{n_{j.}} + \hat{P}_j^2 \sum_{i \neq j}^{q} N_{i.}^2 \frac{n_{ij}}{n_{i.}} \left(1 - \frac{n_{ij}}{n_{i.}}\right) / (n_{i.} - 1) \right]$ ....(eq. 7) where

$$\hat{N}_{.j} = \sum_{i=1}^{q} \frac{N_{i.}}{n_{i.}} n_{ij}$$

is the estimated marginal total number of pixels of reference class *j*, and $N_{i.}$, is the marginal total of map class *i* and n_i.

95% confidence intervals are estimated as $\hat{Y} \pm 1.96\sqrt{\hat{V}(\hat{Y})}$, where $\hat{Y}$ is replaced by $\hat{O}$, $\hat{P}_i$, and $\hat{U}_i$.

The analyses shown above will result in accuracy measures for the land-use interpretation as follows:

Table 10 Error matrix for the first period 2006-2012.

2006-2012		Reference data					
		Forest loss	Forest gain	Stable forest	Stable non-forest	Proportion according to map	Users's accuracy
Map data	Forest loss	$\hat{p}_{11}$	$\hat{p}_{12}$	$\hat{p}_{13}$	$\hat{p}_{14}$	$\hat{p}_{1.}$	$\hat{U}_1, \hat{V}(\hat{U}_1)$, 95% CI
	Forest gain	$\hat{p}_{21}$	$\hat{p}_{22}$	$\hat{p}_{23}$	$\hat{p}_{24}$	$\hat{p}_{2.}$	$\hat{U}_2, \hat{V}(\hat{U}_2)$, 95% CI
	Stable forest	$\hat{p}_{31}$	$\hat{p}_{32}$	$\hat{p}_{33}$	$\hat{p}_{34}$	$\hat{p}_{3.}$	$\hat{U}_3, \hat{V}(\hat{U}_3)$, 95% CI
	Stable non-forest	$\hat{p}_{41}$	$\hat{p}_{42}$	$\hat{p}_{43}$	$\hat{p}_{44}$	$\hat{p}_{4.}$	$\hat{U}_4, \hat{V}(\hat{U}_4)$, 95% CI
Proportion according to reference		$\hat{p}_{.1}$	$\hat{p}_{.2}$	$\hat{p}_{.3}$	$\hat{p}_{.4}$		
Estimated producer's accuracy		$\hat{P}_1$ $\hat{V}(\hat{P}_1)$ 95%CI	$\hat{P}_2$ $\hat{V}(\hat{P}_2)$ 95%CI	$\hat{P}_3$ $\hat{V}(\hat{P}_3)$ 95%CI	$\hat{P}_4$ $\hat{V}(\hat{P}_4)$ 95%CI		
Estimated overall accuracy		$\hat{O}, \hat{V}(\hat{O})$, 95% CI					

3.3.3.4 Area estimation

The area of class *i*, A_i, within the entire inventory area, *A*, is generally given by the proportion of the sub-area, *p*, multiplied by the total inventory area, i.e. $A_i = p_i * A$. The error matrix can be used to calculate sub-areas. However, two alternatives for p_i are presented by the error matrix:

- The estimated proportion $p_{.k}$, which is given by the reference data. As this proportion is based on a sample, it is subject to sample variability.
- The proportion $p_{k.}$, which is obtained from the map and based on the number of pixels falling in class *k*. $p_{k.}$ has no associated sampling variance, but is subject to classification errors.

The two proportions $p_{k.}$ and $p_{.k}$ will not be equal. Therefore, a decision has to be made, which of the two proportions is to be used for the calculation of sub-areas (note: sub-areas are forest loss, forest gain, stable forest, stable non-forest). The bias attributable to reference data is smaller than the bias attributable to map classification error. Therefore, $p_{.k}$ is superior in quality, and reference data should be used for area estimates. However, this renders the inclusion of the associated sampling variances for estimating the related uncertainties necessary.

A direct estimator for the proportion of area of class k based on reference data is

$$\hat{p}_{.k} = \sum_{i=1}^{q} \hat{p}_{ik} \quad \text{(eq. 8)}$$

which is under stratified random or systematic sampling

$$\hat{p}_{.k} = \sum_{i=1}^{q} W_i \frac{n_{ik}}{n_{i.}} \quad \text{(eq. 9)}$$

where W_i is the area proportion of map class *i* and $\hat{p}_{ik} = W_i(\frac{n_{ik}}{n_{i.}})$. This estimator is a poststratified estimator for simple random and systematic sampling, and it is the direct stratified estimator of $p_{\cdot k}$ for stratified random sampling when the map classes are the strata. The variance of $\hat{p}_{.k}$ is estimated by

$$\hat{V}(\hat{p}_{.k}) = \sum_{i=1}^{q} W_i^2 \frac{\frac{n_{ik}}{n_i}\left(1-\frac{n_{ik}}{n_{i.}}\right)}{n_i-1} = \sum_{i=1}^{q} \frac{W_i \hat{p}_{ik} - \hat{p}_{ik}^2}{n_i-1} \quad \text{(eq. 10)}$$

where n_{ik} is the sample count at cell (i,k) in the error matrix and the summation is over the q classes. The 95% confidence interval for $\hat{p}_{.k}$ is obtained by $\hat{p}_{.k} \pm 1.96\sqrt{\hat{V}}(\hat{p}_{.k})$. The estimated area of class k, $\hat{A}_k$, is using the estimated proportion of the reference data, $\hat{p}_{.k}$,

$$\hat{A}_k = A * \hat{p}_{.k} \quad \text{(eq. 11)}$$

with standard error

$$\hat{S}(\hat{A}_k) = A * \sqrt{\hat{V}(\hat{p}_{.k})} \quad \text{(eq. 12)}$$

and the approximate confidence interval

$$\hat{A}_k \pm 1.96\, \hat{S}(\hat{A}_k) \quad \text{(eq. 13)}$$

3.3.4 Combing activity data and emission factors

Area estimates and estimated emission factors will be combined to estimate total emissions from deforestation in natural forests.

Total emissions [tCO_2e] = AD [ha] x EF [$tCO_2e\ ha^{-1}$] .... (eq. 14)

The variance of total emissions will be computed by combining the estimated standard error of the area estimate with the estimated standard error of the emission factor (derived from the Monte Carlo simulation; see Section 3.3.2). In this second Monte Carlo, simulation area estimates will be randomly drawn from the empirical error distribution of the area estimate and will be multiplied by an emission factor estimate that is randomly drawn from the empirical error distribution of the emission estimate. The simulation will have 10,000 runs. The standard deviation of 10,000 total emission estimates will be the standard error of total emissions.

3.4 Emissions from forest degradation

According to the Fijian definition of forest, degradation may occur in both, natural forests and forest plantations. For the FRL, emissions from forest degradation are the emissions that result from selective logging. The applied satellite-based land-use classification method does not further separate forests in open and closed forests. Therefore, the assessment of areas subject to degradation from available image classification is technically not feasible. Therefore, an alternative approach for the estimation of emissions from forest degradation has to be applied.

3.4.1 Quantification of emissions from logging

As forest degradation involves selective logging, the harvested areas were used as a proxy for quantifying the emissions from forest degradation. In Fiji official logging statistics are available which record all timber harvesting realized in concessions under a "Right license". Two different data repositories are used to archive harvesting information:

(1) **Timber Revenue System Database (TRS)**: Harvested volume is obtained by the measurement of logs in the field and transferred to the TRS. The information contained in the TRS includes concession number, timber volume logged and year of logging. The area of the concession license is not available in the TRS.

(2) Harvested Area Reporting (HAR): The HAR contains GPS measurements of the areas logged. The measurements are provided by local foresters. Areas are available as shape files.

The information on harvested timber volume provides the base for the assessment of emissions from forest degradation. From the TRS the total harvested volume can be calculated for the years 2006 to 2016. As the total harvested volume is known no further consideration of the logged area is required. However, the logged area is to be excluded from the forest change mapping in order to avoid double counting (e.g., an area that was logged may cause emissions from forest degradation and emissions from deforestation, i.e., emissions are counted twice). This will be realized by merging the shape files of the HAR with the land-use map of SPC and clipping out the harvested areas from the land-use map.

The harvested volume will be converted into CO_2e by multiplying the volume with the wood density to obtain the biomass, by multiplying the biomass with a factor of 0.47 to get the carbon content and by expanding the carbon content by a factor of 44/12 to get the emissions in CO_2e. As information on volumes per tree species is not available the average wood density of commercial species will be derived from species lists used for the PSP and NFI taking into account species distribution and species specific gravity.

Harvested wood products (sometimes considered as an additional carbon pools) will not be considered for the FRL construction and the extracted volume will be regarded as direct emissions. Besides emissions due to the timber volume removed from the forest two additional sources of emissions have to be considered

(1) damaged biomass in the process of logging; represents the carbon in the aboveground and belowground biomass of the stump and top of the timber tree felled and left as dead wood in the forest, trees incidentally killed or severely damaged (i.e. uprooted or snapped), and large branches broken off from surviving trees during tree felling, and

(2) damaged biomass resulting from infrastructure construction necessary for logging.

Following a proposal from Pearson et al. (2014), these two sources can be transferred into a logging damage factor (LDF) and an infrastructure damage factor (LIF) which can be combined to the total emission factor (TEF),

TEF = LDF + LIF .... (eq. 15)

Haas (2015) studied the carbon emissions caused by logging in Fiji and derived respective emission factors for selective (TEF=0.89) and conventional logging (TEF=1.05). Those factors are below factors reported for the Republic of Congo, Indonesia, or Brazil (Pearson et al., 2014). According to Hass (2015) this is caused by the logging intensities, which are higher in Fiji than in other tropical regions studied, and by including the BGB. The total emissions, E, are calculated via

E=(TEF*carbon logged)+carbon logged .... (eq. 16)

The TEF developed by Haas (2015) and Pearson et al. (2014) do no show substantial differences. Therefore it was decided to take the average of both. In further applications the TEF has to be impoved.

3.4.2 Uncertainty assessment for emissions from logging

Logging areas and logging volumes are assessed as full tallies and thus not subject to sampling variability. The uncertainty assessment will thus only address the uncertainty associated with transferring timber volumes into carbon content and associated CO_2e emissions, i.e. the selection of the wood density and the TEF.

To estimate the uncertainty attached to the emissions from logging, another Monte Carlo simulation will be conducted. In the simulation, random draws of TEF and wood density will be selected from a Gaussian distribution and emissions from logging will be recalculated 10,000 times. The parameters of the distribution (mean and variance), from which the random numbers are drawn during each simulation run, will be derived from Haas (2015) and Pearson et al. (2014). The (relative) standard error of the logging emission estimate will be the standard deviation of the simulated 10,000 emission estimates.

3.5 Emissions and removals from management of plantations

Emissions and removals from plantations (pine and mahogany) will be estimated using data that are made available by Fiji Pine Limited and Fiji Hardwood Corporation Limited.

Plantations in the scope of establishing the FRL are those areas managed by Fiji Pine Limited and Fiji Hardwood Corporation Limited (i.e., subcategory “Plantation Forest”). They are generally even-aged, single species stands that originate from planting. The total area of plantations managed under both companies is roughly 142.000 ha (Fiji Pine Ltd.: 85.500 ha, Fiji Hardwood Corporation Ltd.: 56.500 ha). Out of the total area under lease by Fiji Pine Ltd. (85.000 ha) only 23960 ha were stocked in 2016. From the remaining 61.000 ha, roughly 24.000 ha could potentially be stocked, the rest is not available for replanting, as it is located in rocky areas, areas stocked by native species, or high conservation areas. *The data provided by FPL and FHCL is (partly) available, but serious flaws have been detected, e.g., no harvesting of FPL in 2012!*

The estimation of the total emissions and removals from plantations will take into account three different categories:

- Removals from growth of remaining stand,
- Removals from areas planted within 2006 and 2016, and
- Emissions from areas cut between 2006 and 2016.

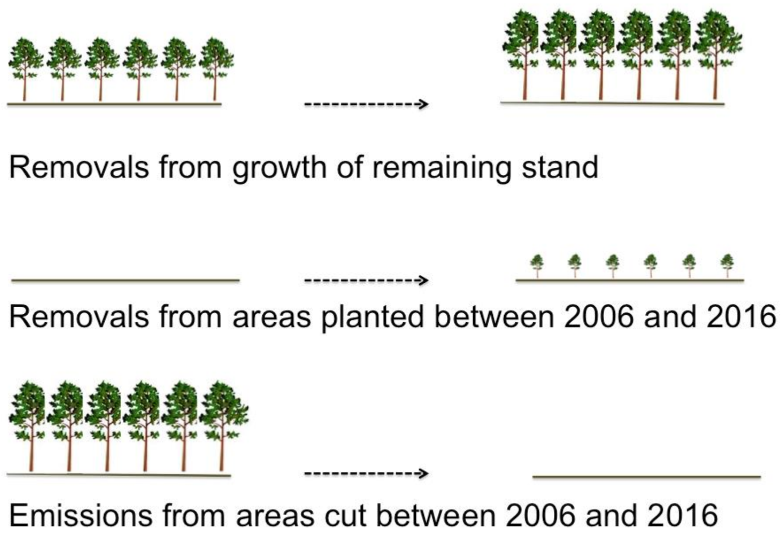

Figure 8 Emissions and removals from plantations.

3.5.1 Removals from growth of remaining stand

Removals from tree growth in remaining stands is calculated separately for the remaining stands of Fiji Pine Ltd. and Fiji Hardwood Corporation Ltd. Remaining stand is a term used for plantation areas that are continuously stocked during the entire period from 2006 to 2016. The area of the remaining stand, A_{rs}, is obtained by

$A_{rs} = A_t - A_u - A_L - A_P$ .... (eq. 17)

where

A_t = total plantation area under lease

A_u = plantation area under lease but unstocked

A_L = plantation area logged between 2006 and 2016

A_P = plantation area planted between 2006 and 2016

Emission/removal factors can be calculated (1) by growth functions giving the current volume of a stand as a function of stand age, or (2) via the mean annual increment as the ratio between harvested volume and stand age. Carbon stock values per hectare and stand age have been presented by Payton and Weaver (2011) for pine and mahogany. Figure 9 presents the carbon stock values from Payton and Weaver (2011) and the two respective carbon stocks derived from logging records of Fiji Hardwood Corp. Ltd. As the sources of the Payton and Weaver's (2011) carbon stock values remain unclear and in order to provide conservative and consistent estimates, it was decided not to consider further those estimates. In consequence, mean annual increment as derived from logging records will be used for the calculation of removals of the remaining stands in plantation areas.

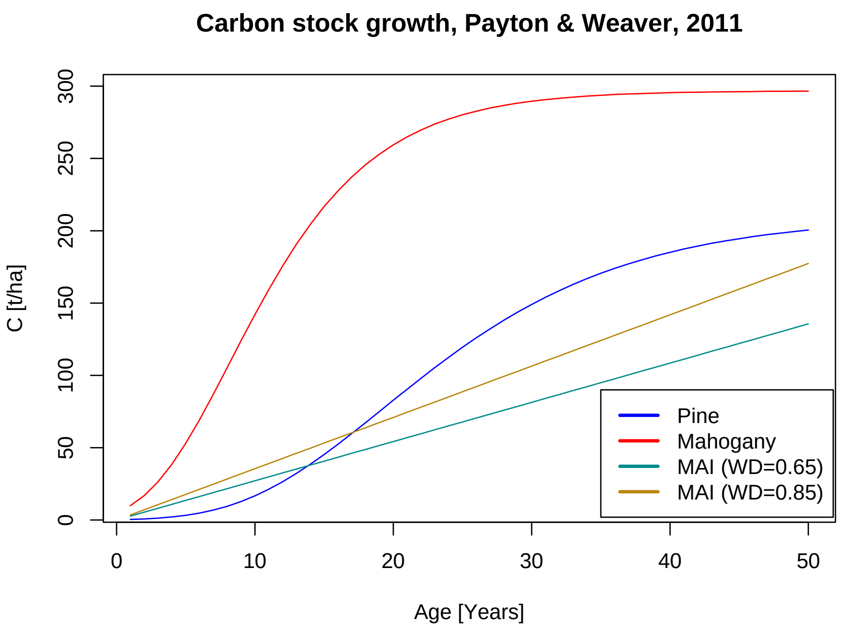

Figure 9: Carbon stock over age according to Payton and Weaver (2011) and mean annual increment (MAI) for mahogany provided by Fiji Hardwood Corporation.

The mean annual increment (MAI) is

$$MAI = F_L \sum_{i=1}^{n} \frac{V_{Li}}{(Year_{Li} - Year_{Pi}) * A_{Li}} \quad \text{(eq. 18)}$$

where

MAI = Mean annual increment in [m^3/ha]

V_{Li} = logged volume on stand *i*

$Year_{Li}$ = year when stand *i* was logged

$Year_{Pi}$ = year when stand *i* was planted

A_{Li} = logged area of stand *i*

F_L = factor to correct for logging losses

n = number of logged stands between 2006 and 2016

The factor F_L is introduced factor to account for logging losses, which remain on the plantations.

In the next step the *MAI* is converted to per hectare biomass growth, i_B, by applying a biomass expansion factor, BEF to obtain *AGB*, and a root:shoot ratio to obtain *BGB*

$$i_B = AGB + BGB = (MAI * BEF) * (1+R) \quad \text{(eq. 19)}$$

Per hectare biomass growth is multiplied by the total area of remaining stands (i.e. between 2006 and 2016), A_{rs}, in order to obtain the total removals due to tree growth in plantation areas, E_{rs}.

$E_{rs} = A_{rs} * i_B$ .... (eq. 20)

From the E_{rS} values removals in terms of C and CO_2e can be calculated.

E_{rs} and associated CO_2e are to be calculated separately for areas under management by Fiji Pine Ltd. and Fiji Hardwood Corp. Ltd. and added to obtain the total removals from the remaining stands.

3.5.2 Removals from areas planted within 2006 and 2016

Replanting of plantation area was realized in any of the years between 2006 and 2016. As the areas replanted in individual years differ as well as the growth rates at different stand ages the year of planting of individual stands has to be taken into account when estimating removals from replanting. This is realized by multiplying the areas replanted in a distinct year i, A_{Pi}, with the annual growth rate in the years following the plantation year until 2016, i_{vi}. Thus, the total volume growth of areas planted between 2006 and 2016, V_{Ptot}, is

$V_{Ptot} = \sum_{i=2006}^{2016} A_{Pi} \sum_{j=1}^{2016-i} i_{vj}$ .... (eq. 21)

V_{Ptot} is converted into total biomass following the procedure given in 2.5.1, and subsequently C and CO_2e are calculated.

V_{Ptot} and associated CO_2e removals from planting are to be calculated separately for areas under management by Fiji Pine Ltd. and Fiji Hardwood Corp. Ltd. and added to obtain the total removals from areas planted.

3.5.3 Emissions from areas cut between 2006 and 2016

From the records of Fiji Pine Ltd. and Fiji Hardwood Corp. Ltd, the volume harvested in the period 2006 to 2016 can be obtained. The total harvested volume is expanded to *AGB* by means of the biomass expansion factor, BEF, and the respective wood density for pine, mahogany and other relevant species. Applying the root-shoot ratio the *BGB* is obtained. The sum of *AGB* and *BGB* gives the total biomass removed by logging, B_L. Transferring the total biomass into total C and CO_2e gives the total emissions from logging activities.

$V_L = \sum_{i=2006}^{2016} V_{Li}$ .... (eq. 22)

$B_L = AGB_L + BGB_L = (V_L * \text{BEF}) * (1+\text{R})$ .... (eq. 23)

where

V_L = total volume logged

V_{Li} = volume logged in year i, i={2006,…,2016}

AGB_L = above ground biomass logged

BGB_L = below ground biomass logged

B_L and associated CO_2e from logging activities are to be calculated separately for areas under management by Fiji Pine Ltd. and Fiji Hardwood Corp. Ltd. and added to obtain the total removals from the remaining stands.

3.5.4 Total emissions/ removals from plantation areas

Emissions/ removals (1) growth of remaining stand, (2) areas planted, and areas cut between 2006 and 2016 have to be combined in order to achieve the total emissions/ removals from plantation management. Table 11 summarizes the necessary calculations. The 95%-CI are obtained from the uncertainty analysis.

Table 11 Calculation of ermissions/ removals from plantation areas.

Source		Fiji Pine Ltd. CO_2e [t $ha^{-1}a^{-1}$]	Fiji Hardwood Corp. Ltd. CO_2e [t $ha^{-1}a^{-1}$]
Remaining stand	Total		
	95% CI		
Plated areas	Total		
	95% CI		
Logged areas	Total		
	95% CI		
Total	Total		
	95% CI		
Grand total	Grand total		
	95% CI		

3.5.5 Uncertainty analysis

The plantation areas are obtained from terrestrial surveying and available in mapped format. As they are subject to negligible measurement errors only, no uncertainty assessment for the plantation areas will be carried out. Harvesting is generally realized as clear cut resulting in temporarily unstocked areas. Those unstocked areas are considered as plantation area, for what reason clearcutting does not result in deforestation. To remain consistent *plantation areas have to be removed from the land use map* to avoid double counting.

Uncertainty analysis will address the errors associated with emission factors. In the calculation of biomass values uncertainty is introduced by assumptions on wood densities, WD, and root:shoot ratios, R. Logging volumes are measurements and thus not subject to uncertainties. In estimating the growth of the remaining stand and planted areas assumptions have to made concerning tree growth, which introduce uncertainty.

An MC simulation will be conducted to assess the uncertainty attached to emission/removal estimates from plantations. That is, 10,000 simulation runs were random error is added to values of wood density, root:shoot ratios, and estimates of growth (i.e., MAI).

4 Estimation of Forest Reference Level (FRL)

The estimation of the FRL is based on historical data, which are available for 2006-2007 (EF from NFI) as well as 2006, 2012 and 2016 (AD from satellite imagery). For plantations and logging areas annual data are available for the period 2006 to 2016. The data are representative for the accounting area. From these data historical emissions and removals will be derived. The emissions and removals are averaged. Given the length of the reference period the time available for the average is representative of current conditions. There is no systematic variation in the data. Therefore, the prerequisites for using the historical average are satisfied.

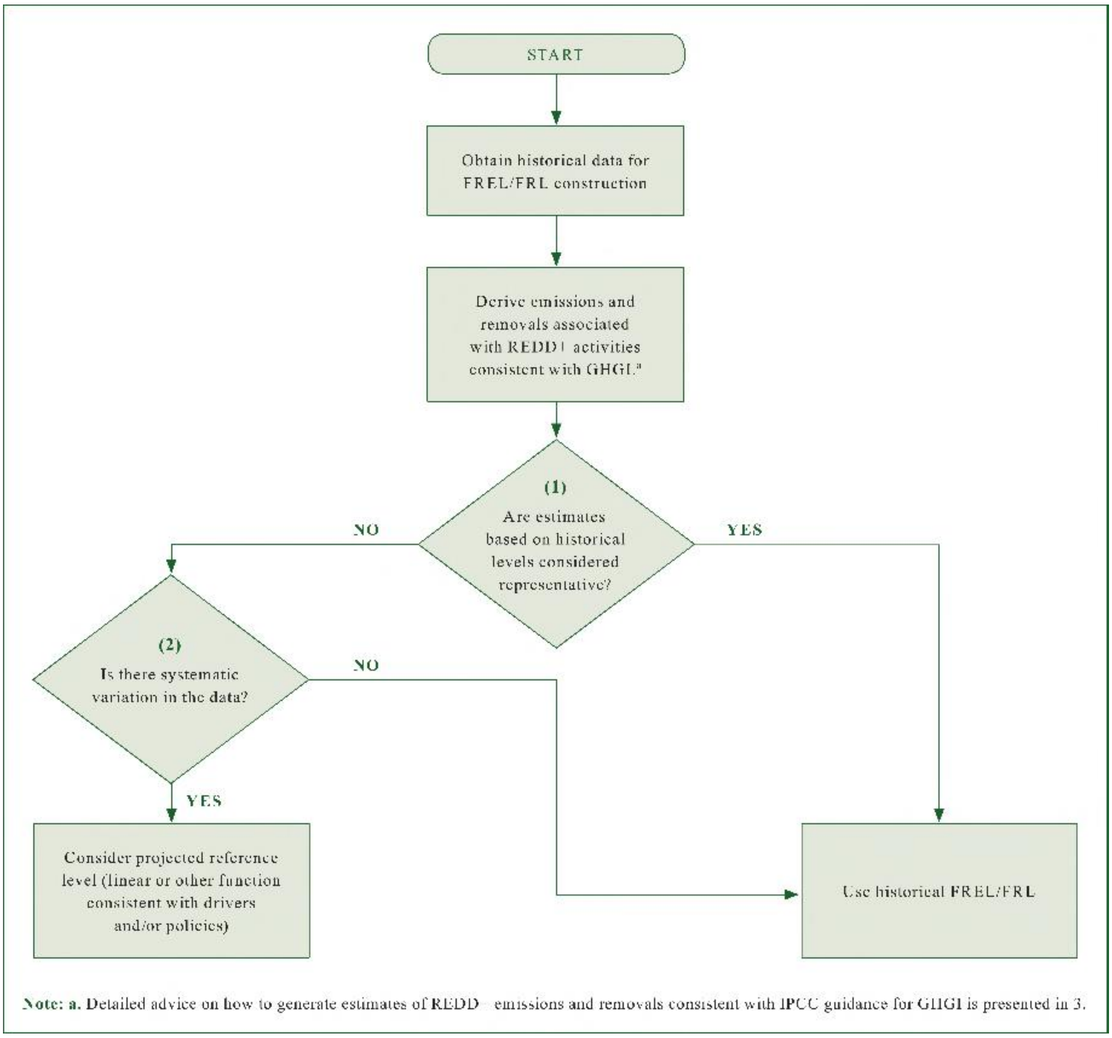

Figure 10 Use of historical data for developing FREL/FRLs (GFOI, 2016)

4.1 Historical emissions/removals

In the first place emissions and removals are calculated for three subclasses:

- Emissions from deforestation and afforestation (using NFI data and remote sensing imagery)
- Emissions from forest degradation (using logging records as proxies)
- Emissions from plantations
- Removals from plantations

The emissions/removals will be combined as shown in Table 13. The values that will be presented in the second column will include estimates of variance (i.e., the lower and upper 95% confidence limits).

Table 11 Example of a table showing results of the estimated emissions by subgroup.

Subgroup	Emissions/removals CO_2e [t $ha^{-1}a^{-1}$]	Comment
Emissions from deforestation and afforestation in natural forests (see 2.3)		Data sources: NFI 2005 and land-use change classification 2006-2016 Gain-loss method Emissions = AD *EF
Emissions from logging in natural forests (see 2.4)		Total logged volume 2006 to 2016
Emissions and removals from management of plantations (see 2.5)		Total emissions/removals from plantations
Total historic emissions/removals	Σ	

4.2 Updating frequency

In line with the UNFCCC decision 12/CP. 17,paragraph 10, Fiji's FRL estimation follows a stepwise approach, aiming to improve FRL accuracy overtime by incorporating better data, improved methodologies and, when appropriate, additional pools. Fiji will therefore follow a periodic cycle in updating its FRL, ensuring consistency with the NFI. In addition, Fiji will make efforts to enhance capacity to estimate emissions/removals from mangrove forests and forest degradation. These efforts will be applied particularly during the period 2018-2023 so that additional knowledge can be acquired for the modification of FRL scope and methodologies. Specific areas for future improvement are presented in the following section.

4.3 Future improvements

Specific areas for improvement of the FRL have been identified, on which Fiji is advised to continue investigation, data collection and testing of methodologies, dependent on available resources. These are the following:

- Replace the indirect assessment of forest degradation through logging concession data by cost-effective direct measurements of forest degradation by advanced remote sensing technologies, which allow for consistent and sufficiently accurate monitoring of closed and open forest cover over time.

- Fully include the activity forest carbon stock enhancement on forest land remaining forest land. This would allow Fiji to report on the important results of improved forest management achieved in the country.
- Improve the allometric functions for the estimation of above-ground biomass.
- Include measurements for the assessment of the carbon pools litter, dead wood and soil organic carbon.
- Develop and implement a NFI concept that allows for representative, reliable and consistent assessment of current values and changes of forest biomass and carbon stock.

Develop and implement methods for utilizing improved remote sensing technologies for land-use change assessments and detection of forest degradation.

Implement initiatives for capacity building with respect to field assessments, remote sensing image analysis, IT-technology (incl. database management) and sampling statistics.

5 Compliance with IPCC Principles (of Good practice) and FCPF Carbon Fund Methodological Framework

5.1 Compliance with IPCC Principles

IPCC good practice guidance (IPCC, 2003b, 2006) assists countries in producing inventories that are accurate in the sense of being neither over nor underestimated as far as can be judged, and in which uncertainties are reduced as far as practical. One of the elements that contribute to the overall improvement of the inventories is that both IPCC and UNFCCC guidelines include the principles of transparency, consistency, comparability, completeness and accuracy (TCCCA) as guiding principles in preparing and reporting inventories. These principles are applicable for the FRL-construction as well.

Transparency means that the assumptions and methodologies used for an inventory should be clearly explained to facilitate replication and assessment of the inventory by users of the reported information. The present FRL is transparent as all required information for its construction is given and allows for the reconstruction at any time.

Consistency means that an inventory should be internally consistent in all its elements with inventories of other years. An inventory is consistent if the same methodologies are used for the base and all subsequent years and if consistent data sets are used to estimate emissions or removals from sources or sinks. The FRL in its current stage follows a step-wise approach. Data available at the time of its construction are consistently used. Future improvements need to take into account existing methodology.

Comparability means that estimates of emissions and removals reported by Parties in inventories should be comparable among Parties. For this purpose, Parties should use the methodologies and formats agreed by the COP for estimating and reporting inventories. The allocation of different source/sink categories should follow the split of the IPCC Guidelines, at the level of its summary and sectoral tables. The current FRL implements the methodology given by IPCC for the LULUCF and AFOLU sector. Therefore, results are comparable with those from other Parties implementing the IPCC guidance.

Completeness means that an inventory covers all sources and sinks, as well as all gases, included in the IPCC Guidelines as well as other existing relevant source/sink categories which are specific to individual Parties and, therefore, may not be included in the IPCC Guidelines. Completeness also means full geographic coverage of sources and sinks of a Party. The current FRL includes only CO_2e. Other GHG are not included as they play a minor role in Fiji's forests. The accounting area covers roughly 90% of Fiji's forested area. Under a step-wise approach completeness can be assumed for the FRL at its current stage.

Accuracy is a relative measure of the exactness of an emission or removal estimate. Estimates should be accurate in the sense that they are systematically neither over nor under true emissions or removals, as far as can be judged, and that uncertainties are reduced as far as practicable. To promote accuracy in the available data and analysis procedures appropriate methodologies have been implemented, in accordance with the IPCC good practice guidance, to promote accuracy of the emission/ removal estimates.

5.2 Compliance with FCPF Carbon Fund Methodological Framework

The Forest Carbon Partnership Facility of the World Bank has published a Carbon Fund Methodological Framework (MF) that provides guidance to the development and selection of REDD+ Programs (FCPF, 2016). For the construction of a FRL the MF presents four criteria and ten indicators, which are listed and discussed below.

Criterion 10: The development of the Reference Level is informed by the development of a Forest Reference Emission Level or Forest Reference Level for the UNFCCC.

Indicator 10.1: The Reference Level is expressed in tonnes of carbon dioxide equivalent per year.

Fullfilled for Fiji's FRL. The reference level will be expressed in tonnes of CO_2e.

Indicator 10.2: The ER Program explains how the development of the Reference Level can inform or is informed by the development of a national Forest Reference Emission Level or Forest Reference Level, and explains the relationship between the Reference Level and any intended submission of a Forest Reference Emission Level or Forest Reference Level to the UNFCCC.

A national FRL will be constructed, which includes roughly 90% of the total forest area of Fiji. The same FRL-construction will be used by the ER-Program.

Indicator 10.3: The ER Program explains what steps are intended in order for the Reference Level to achieve consistency with the country's existing or emerging greenhouse gas inventory.

Consistency is maintained as the same forest area definition is used.

Criterion 11: A Reference Period is defined.

The reference period is defined. It covers the time period from 2006 to 2016.

Indicator 11.1: The end-date for the Reference Period is the most recent date prior to two years before the TAP starts the independent assessment of the draft ER Program Document and for which forest-cover data is available to enable IPCC Approach 3. An alternative end-date could be allowed only with convincing justification, e.g., to maintain consistency of dates with a Forest Reference Emission Level or Forest Reference Level, other relevant REDD+ programs, national communications, national ER program or climate change strategy.

The end date of the reference period is two years before the TAP starts. ER-PD will be submitted by October 2018, the first meeting of TAP will probably be in mid-2019. The reference period ends in 2016.

Indicator 11.2: The start-date for the Reference Period is about 10 years before the end-date. An alternative start-date could be allowed only with convincing justification as in Indicator 11.1, and is not more than 15 years before the end-date.

The start date (2006) of the reference period is ten years before the end date (2016).

Criterion 12: The forest definition used for the ER Program follows available guidance from UNFCCC decision 12/CP.17.

Indicator 12.1: The definition of forest used in the construction of the Reference Level is specified. If there is a difference between the definition of forest used in the national greenhouse gas inventory or in reporting to other international organizations (including an

Forest Reference Emission Level or Forest Reference Level to the UNFCCC) and the definition used in the construction of the Reference Level, then the ER Program explains how and why the forest definition used in the Reference Level was chosen.

The forest area definition is specified. The construction of the FRL uses the same forest definition as it was used in the Second National Communication to the UNFCCC, 2013 submitted by the Republic of Fiji .

Criterion 13: The Reference Level does not exceed the average annual historical emissions over the Reference Period. For a limited set of ER Programs, the Reference Level may be adjusted upward by a limited amount above average annual historical emissions. For any ER Program, the Reference Level may be adjusted downward.

Indicator 13.1: The Reference Level does not exceed the average annual historical emissions over the Reference Period, unless the ER Program meets the eligibility requirements in Indicator 13.2. If the available data from the National Forest Monitoring System used in the construction of the Reference Level shows a clear downward trend, this should be taken into account in the construction of the Reference Level.

The FRL does not exceed the annual historical emissions over the reference period.

Indicator 13.2: The Reference Level may be adjusted upward above average annual historical emissions if the ER Program can demonstrate to the satisfaction of the Carbon Fund that the following eligibility requirements are met:

i. Long-term historical deforestation has been minimal across the entirety of the country, and the country has high forest cover;

ii. National circumstances have changed such that rates of deforestation and forest degradation during the historical Reference Period likely underestimate future rates of deforestation and forest degradation during the Term of the ERPA.

No adjustments to national circumstances will be made.

Indicator 13.3: For countries meeting the eligibility requirements in Indicator 13.2, a Reference Level could be adjusted above the average historical emission rate over the Reference Period. Such an adjustment is credibly justified on the basis of expected emissions that would result from documented changes in ER Program circumstances, evident before the end-date of the Reference Period, but the effects of which were not fully reflected in the average annual historical emissions during the Reference Period. Proposed adjustments may be rejected for reasons including, but not limited to:

i. The basis for adjustments is not documented; or

ii. Adjustments are not quantifiable.

Not applicable, as no adjustments to national circumstances will be made.

Indicator 13.4: An adjustment of the Reference Level above the average annual historical emissions during the Reference Period may not exceed 0.1%/year of Carbon Stocks.

Not applicable, as no adjustments to national circumstances will be made.

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