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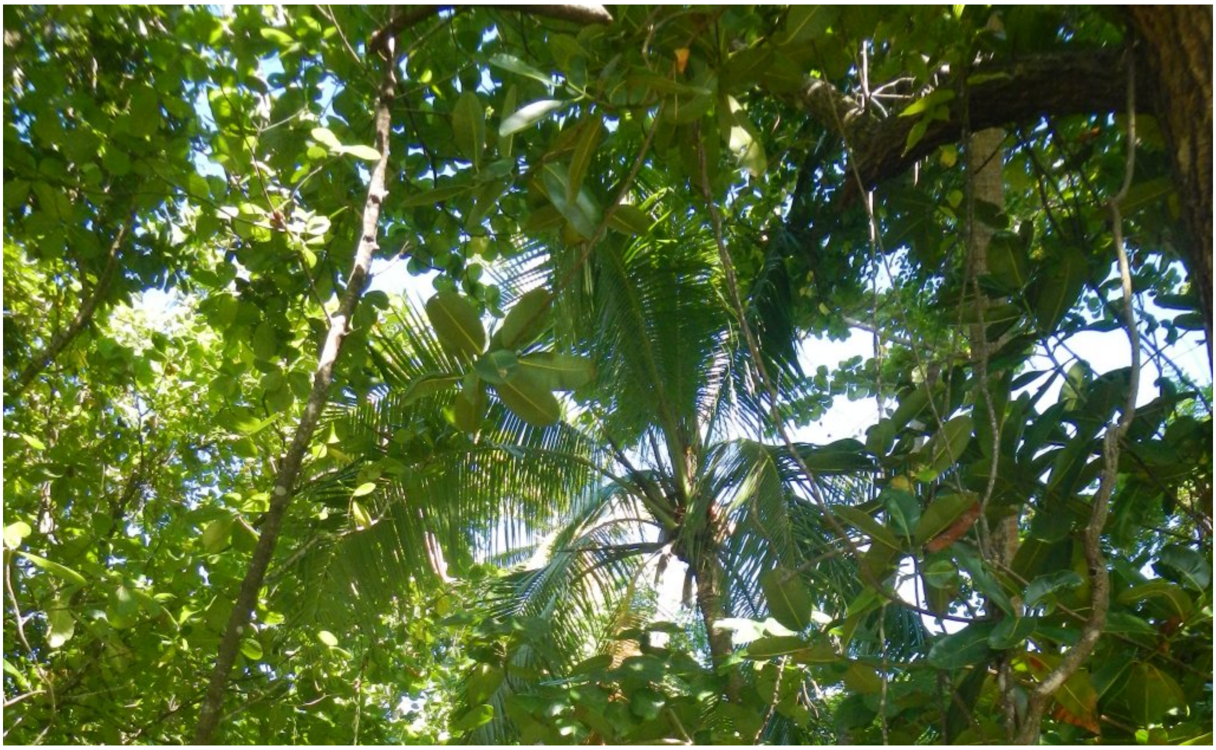

Carbon Emissions from Forest Degradation caused by Selective Logging in Fiji

SPC Secretariat of the Pacific Community

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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On behalf of:

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

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Executive summary

The present report was developed by the regional SPC / GIZ project "Climate Protection through Forest Conservation in Pacific Island Countries", which supports Fiji in the preparation for participation in the international compensation mechanism to reduce emissions from deforestation and forest degradation (REDD+) under the United Nations Framework Convention on Climate Change (UNFCCC).

Although there is general consensus that the current rates of deforestation and degradation are modest compared to some neighbouring Pacific nations, Fiji has experienced significant forest loss and forest degradation in the past. The latter is expected to contribute the most important share to the greenhouse gas emissions from the forest sector, but the dimension is still poorly understood. Commercial selective logging represents the most important driver of natural forest degradation, particularly because logging practice is generally unregulated and unsustainable, resulting in declining timber resources and ecosystem services. Although Fiji´s harvesting regulatory framework, the 2013 Forest Harvesting Code of Practice, has been amended to include RIL standards, these are not being implemented on the ground due to insufficient technical capacities of the logging companies and lacking enforcement by the responsible government agencies.

In this study, the carbon emissions from Sustainable Forest management (SFM) and conventional logging demonstration activities are estimated by means of activity-related emission factors relative to the m^3 of harvested timber. The three main emitters are the logs and associated waste biomass, the damage to the residual stand and the installation of the logging infrastructure. Emission factors range from 0.76-1.3 t C per m^3 and are negatively correlated with the extraction rate: The lower the extraction rate, the higher are the emissions per m^3 of extracted timber. Emission factors from conventional logging are shown to be on average 13% higher than from SFM. The majority of emissions is caused by the log extraction and associated waste biomass, followed by the logging infrastructure, and lastly the damage to the residual stand. The results from Fiji are comparable in dimension to emission factors from selective logging in tropical Africa, Asia and Latin America, which range from 0.99-1.49 t C per m^3.

In order to estimate emissions from selective logging at national level, the emission factors were combined with national log production data from natural forests. The log production in Fiji averages 62,500 m^3 per year, causing emissions of approximately 252,000 t CO_2. In comparison, emissions from deforestation are only 33,000 t CO_2 per year, due to less than 0.1% annual forest cover loss. Although emissions from selective logging are modest, the activity bears the most significant potential for carbon benefits from the forest sector in Fiji.

Fiji is currently in the second phase of its national REDD+ program and in the process of developing REDD+ strategy options that target the implementation and enforcement of SFM activities in compliance with the FFHCOP. Demonstration activities have shown that SFM with REDD+ compensation is more attractive than conventional logging or total forest conservation from macro-economic and climate change perspectives and in terms of benefits for the involved stakeholders. The implementation of SFM activities, mainly the regulation of the logging intensity and the reduction of avoidable timber waste, potentially leads to avoided emissions of 165,000 t CO_2 per year. Additional carbon benefits arise from the reduction of illegal logging, because of the increased enforcement of the forest regulations. The carbon benefits from SFM are significantly enhanced by the associated co-benefits, especially the restoration and maintenance of forest resources potential and ecosystem services.

In line with Fiji´s National REDD+ program, subsequent steps in the REDD+ Readiness process will be the design of the National Forest Monitoring System (NFMS), and the Measuring, Reporting and Verification (MRV) system, which will allow for regular and systematic quantification and monitoring of net emissions and removals associated with the different REDD+ activities. In the Fijian context, it will be important to maintain the complexity and associated costs of the forest degradation component in proportion to the modest magnitude of avoidable emissions and the capacities of the responsible government agencies.

Contents

Executive summary ... **3**

Abbreviations ... **6**

1 Introduction ... **7**

1.1 Background ... 7

1.2 Objectives ... 7

1.3 Description of the Forest Sector in Fiji ... 8

1.4 Drivers of Change that affect Forests ... 10

2 Methodology ... **13**

2.1 Relevant Carbon Pools ... 14

2.2 Emission Factor Calculation ... 14

2.3 Comparison of Emissions from Forest Degradation and Deforestation ... 15

2.4 Assumptions made for the REDD+ Scenario Conventional Logging to SFM ... 16

2.5 Available Datasets ... 16

3 Emission Factors from Selective Logging ... **17**

3.1 Key Logging Statistics ... 17

3.2 Emission Factor Analysis ... 17

4 Comparison of Logging Emission Factors in Fiji with Results from other Case Studies ... **19**

5 Emissions from Selective Logging compared to Emissions from Deforestation ... **20**

6 Contributions to the REDD+ Strategy Option "SFM and forest enhancement activities" ... **22**

References ... **25**

Appendices ... **26**

Appendix A: Description of the Nakavu Forest Management Pilot Site (NFMPS) ... 26

Appendix B: Models and Parameters used in Carbon Calculations ... 27

Appendix C: Complete Emission Factor Results from all Logging Treatments ... 28

Tables

Table 1: Fiji's natural and plantation forest area (2005-2008). 8
Table 2: Land tenure of natural forest areas in Fiji. 10
Table 3: Drivers of deforestation in Fiji, estimated carbon impacts, and countermeasures. 12
Table 4: Drivers of forest degradation in Fiji, estimated carbon impacts and countermeasures. 13
Table 5: Relevant carbon pools for estimating carbon emissions from logging degradation in Fiji. 14
Table 6: Description of emission factors from selective logging and their respective components. 15
Table 7: Key logging statistics from the SFM / REDD+ pilot site in Nakavu, Fiji. 17
Table 8: Emission factors from SFM and conventional logging in Fiji. 17
Table 9: Logging emission factors from Fiji compared to results from selective logging in tropical Africa, South East Asia and South America. 19
Table 10: Annual deforestation and associated carbon emissions in Fiji. 20
Table 11: Emissions from logging degradation and deforestation in Fiji. 21
Table 12: Simulation of a jurisdictional REDD+ scenario, based on a transition from conventional logging to sustainable forest management. 23
Table 13: Stand volume and extraction rate per compartment and per logging regime in the NFMPS. 27
Table 14: Models and parameters used in the carbon calculations. 28
Table 15: Results of the emission factor analysis (separate for all logging regimes). 28

Figures

Figure 1: Log production from natural and plantation forests (pine and mahogany) in Fiji. 9
Figure 2: Correlation between the logging emission factor and the timber extraction rate. 18
Figure 3: Scatter plot diagram demonstrating the relation between logging emission factors and the timber extraction rate in Fiji and other case studies. 19
Figure 4: Proportion of per-ha emissions from felling, logging infrastructure and damage at different extraction rates. 22
Figure 5: Map of NFMPS and compartment subdivision. 26

Abbreviations

AGB	Above-ground biomass
BGB	Below-ground biomass
BMUB	German Federal Ministry for Building, Environment and Nuclear Safety
CNV	Conventional logging
DBH	Diameter at breast height
DLT	Diameter limit table
FAO	United Nations Food and Agriculture Organization
FCPF	Forest Carbon Partnership Facility
FD	Fiji Forest Department
FFHCOP	Fiji Forest Harvesting Code of Practice
FJD	Fijian dollar
FRA	FAO global forest resources assessment
GIZ	Deutsche Gesellschaft fuer Internationale Zusammenarbeit
IPCC	International Panel on Climate Change
MRV	Measuring, reporting and verification system
NFMPP	Nakavu Forest Management Pilot Project
NFMPS	Nakavu Forest Management Pilot Site
NFMS	National forest monitoring system
PES	Payment for ecosystem services
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
RIL	Reduced-impact logging
R-PP	FCPF readiness preparation proposal
SFM	Sustainable forest management
SPC	Secretariat of the Pacific Community
TLTB	iTaukei Land Trust Board
UNFCCC	United Nations Framework Convention on Climate Change
VCU	Verified carbon unit
WD	Wood density

1 Introduction

1.1 Background

The present report was developed by the regional SPC / GIZ project "Climate Protection through Forest Conservation in Pacific Island Countries", which supports Fiji in the preparation for participation in the international compensation mechanism to reduce emissions from deforestation and forest degradation (REDD+) under the United Nations Framework Convention on Climate Change (UNFCCC).

Fiji consists of over 300 islands, of which 100 are inhabited. The cluster of islands lies just inside the southern tropical belt near the 180th meridian and comprises a land area of 1.83 million hectares[1]. The two main islands and a few smaller islands have mountainous interiors covered with dense natural forest resources that amount to 1.1 Million hectares or 60% of the land area.

Although there is general consensus that the current rates of deforestation and degradation are modest compared to some neighbouring Pacific nations, Fiji has experienced significant forest loss and forest degradation in the past. Emissions from forest degradation are expected to constitute the most significant share of the greenhouse gas emissions from the forest sector. The accurate assessment of forest degradation represents a challenging and costly task, which is why its magnitude is still poorly understood at national level. The most important driver of forest degradation in Fiji is commercial logging, particularly because logging practice is generally unregulated and unsustainable and law enforcement is weak.

Fiji endorsed its national REDD+ policy in 2010 and is currently in the second phase of its national REDD+ program, which includes the establishment of pilot sites and strengthening technical Measuring, Reporting and Verification (MRV) capacities as well as the development of a national REDD+ strategy. This report aims to support the development of the REDD+ strategy option "SFM and forest enhancement activities".

1.2 Objectives

The central elements of this report are the estimation of carbon emissions from natural forest degradation caused by selective logging, and the assessment of the carbon benefits of a transition from conventional logging to SFM at national level in Fiji. The structure of this report is guided by the following objectives:

1. Develop activity-related, per-m^3 emission factors using data from SFM demonstration activities:
   - Compare emission factors between SFM and conventional logging at different extraction rates;
   - Compare emission factor results from Fiji to studies from tropical timber-producing countries in Asia, Africa and Latin America.

2. Estimate the magnitude of emissions from selective logging at national level using emission factors and log production data:
   - Compare emissions from selective logging and from deforestation;
   - Assess the current and future impacts of the drivers that affect forest degradation and deforestation.

3. Assess the carbon benefits of a transition from conventional logging to SFM in a jurisdictional REDD+ context:
   - Analyse the forest sector consequences of a broad implementation of SFM activities;
   - Support the development of the REDD+ strategy option "SFM and forest enhancement activities".

[1] Source: FAO Fiji Forestry Outlook Study, 2010.

1.3 Description of the Forest Sector in Fiji

1.3.1 Forest Resources

According to results from the national forest inventory, Fiji's forests cover an area of about 1.1 Million hectares, representing 60% of the total land area. The forests can be classified into two main categories: First, natural forests composed of native tree species and secondly, plantation forests composed of exotic softwood (*Pinus caribea*) and hardwood (*Swietenia macrophylla*) species. The latter were established within the scope of the Fijian Forest Department's research and plantation program in the 1950's and early 60's, in response to decreasing yields from natural forests.

	Multiple-Use Forest (ha)	Protection Forest (ha)	Total Forest Area (ha)	(%)
Closed Forests	487,431	39,021	526,453	48%
Open Forests	371,565	16,850	388,415	35%
Mangrove Forests			54,189	5%
Total Natural Forests	**858,997**	**55,871**	**969,057**	**88%**
Softwood Plantations	71,783	880	72,663	7%
Hardwood Plantations	57,931	1,066	58,997	5%
Total Plantation Forests	**129,715**	**1,946**	**137,240**	**12%**
Total Forest Area			**1,106,297**	**100%**
Total Land Area			**1,830,000**	

Table 1: Fiji's natural and plantation forest area (2005-2008)[2].

Natural forests including mangroves cover 969,057 hectares, representing 53% of Fiji's land area, while plantation forests cover 137,240 ha, representing 7% of the land area. While Fiji's mahogany plantations are recognized as possibly the most valuable in the world, natural forests are considered highly degraded and significant reforestation and forest enhancement activities are required to restore productivity.

1.3.2 Economic Role of the Forest Sector

Although the sugar industry and a growing tourist industry are currently the major sources of foreign exchange, Fiji relies heavily on primary industries and the forest sector is an integral part of the economy. Natural resource extraction includes timber, fish, gold, copper, offshore oil potential and hydropower, all sectors that directly or indirectly impact forests. Natural forest ecosystems constitute an important role for the livelihood / subsistence of rural populations through the provision of household goods such as construction material, fuel wood, food products and medicine.

Export earnings from forest products rank third behind the agricultural sectors and contribute an average of 1.2% to the GDP over the past 10 years, generating approximately US$ 40-50 Million in foreign exchange annually. Forestry exports have increased in the past years and the forestry sector is estimated to produce an average of 6.8% of the GDP from 2014 onwards[3]. The most important export timber commodities are woodchips, sawn timber, components, decking, plywood and veneer. Economic returns from forestry exports are currently more than 10 times higher than the expenditures from forestry imports, which consist mainly of posts, poles, hardboards, plywood boards and sawn timber. In 2013, the export revenue from timber and wood-based commodities culminated at US$ 75.7 Million, where pine-wood chips achieved the highest earnings (US$ 33.8 M), followed by sawn timber (mainly mahogany-US$ 30.4 M), components (US$ 4.5 M), decking (US$ 2.9 M), sandalwood (US$ 2.2 M) and plywood (US$ 1.2 M).[4] Over 90% of the exported timber products are processed from exotic plantation (pine and mahogany) species. The main native species

[2] Source: National Forest Inventory, Management Services Division, Forestry Department.
[3] Source: Ministry of Finance, Economic and Fiscal Update & FBIOS.
[4] Source: Licensing Unit, Forestry Department.

processed for export are Dakua makadre, Dakua Salusalu, Kaudamu and Sandalwood, which combined amount to 6% of the forest sector export revenue.

Currently, Fiji's major export and import market for timber products is the Asian market, mainly China (30%) and Japan (16%), followed by the American market dominated by the USA (21%) and the Dominican Republic (18%). At the same time, a significant and growing amount of timber serves local market demand, which stems for the most part from natural forests, as well as smaller quantities of pine. Production and economy of this timber are hard to quantify however, as many domestic sector timber activities fall outside of a legal framework and remain unregulated.

1.3.3 Timber Production and Processing

The log production from selective logging in natural forests in Fiji is on a declining trend, falling from an average annual volume of about 150,000 m³ in the late 80's and 90's to 80,000 m³ from 2000 onwards and declining even further to just over 50,000 m³ after 2006. In 2013, the official log production from natural forests totalled only 38,052 m³. This figure excludes illegal commercial logging and unregulated small-scale log production for domestic use or local sales, which may be significant.

As natural forest production declines, the timber production from forest plantations becomes more important. As a result of the Fijian Forest Department's research and plantation program, a timber production boom of about 500,000 m³ per year occurred during the 90's, after which production fell back to the current average of 364,000 m³ per year.

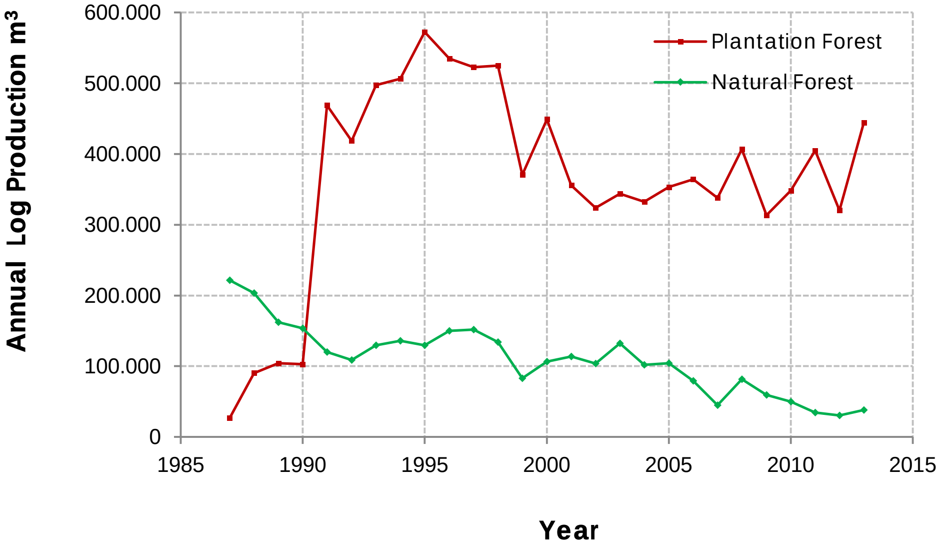

Figure 1: Log production from natural and plantation forests (pine and mahogany) in Fiji[5].

The decline in the log production signals the increasing degradation of Fiji's natural forests, resulting from long-term over-use of timber resources. As a consequence, forest industries are migrating from predominantly natural forest species to smaller-sized logs from pine plantations and medium-sized logs from mahogany stands. Inefficient and non-competitive sawmills have been eliminated in recent years. The remaining sawmills, however, continue to suffer from inadequate capital investment partly due to doubtful future raw material supply. Further processing is limited, with currently only two mills producing plywood and veneer. More value-adding, including furniture making, is carried out in the manufacturing sector, and associated revenues are not attributed to the forestry sector.

[5] Source: The Department of Forests key statistics booklet (2014).

1.3.4 Land and Forest Ownership

About 90% of the land in Fiji is communally owned through traditional Fijian communal landowning units called *mataqali*, whilst the remainder is private and / or state-owned land. A significant development in the Fijian land tenure system was the establishment of the iTaukei Land Trust Board (TLTB), set up in 1940 to act on behalf of landowning *mataqali* to secure, protect and manage land ownership rights and facilitate commercial transaction for its use. The TLTB is the legal custodian and representative of all native land in Fiji.

In terms of forest ownership, 90% of the natural forest belongs to the communities, while industrial plantations of exotic softwoods and hardwoods are grown on leased land and community plantations are being established on communal land, without the need for communal binding agreements.

Land Tenure	Total Natural Forest Area (ha)	(%)
iTaukei Land	854,368	89.9
State Land	40,493	4.3
Private (Freehold) Land	55,530	5.8
Total	**949,991**	**100**

Table 2: Land tenure of natural forest areas in Fiji[6].

Note that ownership of trees does not always coincide with ownership of the land on which they are growing. In the case of mahogany and pine plantations, the companies who lease the plantation land own the trees while *mataqali* retain ownership of the land. The Government owns a 90% share in the mahogany plantations and over 98% in the pine plantations, the rest is owned by indigenous landowners.

1.4 Drivers of Change that affect Forests

The drivers of change that most affect forests and forestry can be categorized as either 'direct drivers' (where the effects are immediate) or 'indirect drivers', which impact forests by catalysing a chain of events. Often, it is the indirect drivers that have the most far-reaching impacts on forests but these are more difficult to quantify. The FAO Asia-Pacific Forestry Sector Outlook 2020 includes a chapter that provides an overview of the main drivers of change likely to affect Pacific forests and forestry through to 2020, which can be categorized into six groups:

- Demographic changes;
- Economic Development;
- Changes in societies' perceptions and demands;
- Environmental changes;
- Technological and scientific advances; and
- Political and institutional evolution.

[6] Source: FAO Global Forest Resources Assessment 2010- Fiji Country Report.

1.4.1 Drivers of Deforestation

Driver	Current Situation (2000-2015)	Future Situation (2015-2030)	Carbon Impact	Measures and Initiatives to address driver
Underlying Driver: Economic Development				
Direct driver: **Agriculture (subsistence and commercial)**	Commercialization of taro and yaqona, ginger, horticulture , with government push for more exports and import substitutions	Trend will increase with current incentives for agriculture (scholarships for agriculture, funds for farming)	Large source	Agro-forestry: Promotes tree planting within agricultural areas, allows food production without forest conversion Projects: Model agro-forestry farms (Drawa)
Direct driver: **Pasture lands**	On-going	Expected to continue with current incentives for dairy farming		
Direct driver: **Mining (Bauxite)**	On-going	Expected to increase due to international demand for mineral	Small source	Re-vegetation of degraded areas (non-forested area to forest land Projects: Reforestation and afforestation-community extension programs
Direct driver: **Tourism - coastal forest reclamation for infrastructure and recreational activities (Denarau, Yasawa Isl., Mamanuca Isl.)**	Increasing in extent (mangrove areas, Naisoso, Natadola)	Trend of tourism infrastructure expansion will continue (Maritime islands, Lau)	Medium source	Eco-tourism & eco-lodges Projects: Community based eco-tourism (Biausevu, Colo-i-suva, Bouma, Abaca, Rain Tree, Nadarivatu)
Direct driver: **Energy production hydro dams for electricity, e.g. Monasavu dam, and for water supply, e.g. Vaturu dam**	Vaturu / Wainikasou	Future plans for Vaturu/ Wainikasou dam for water and energy. Increasing demand for renewable energy (more dams, bio-fuels deforestation) Water dams for Waidina (Sovi basin) and Navua river	Small-medium source	
Underlying driver: Population growth				
Direct driver: Formal & informal settlements, (relocation of villages)	Ongoing trend and continues to increase, e.g. Waila city development, new housing schemes along coasts and new infrastructure	Continues to increase in all types of housing developments, (up class housing, gated communities, settlements, Maui beach resort, tourism), James town development in mangrove area	Medium source	Improved spatial planning prior to infrastructure development (zoning) Establishment of conservation areas e.g. parks and reserves

Driver	Current Situation (2000-2015)	Future Situation (2015-2030)	Carbon Impact	Measures and Initiatives to address driver
Underlying driver: Governance				
Direct driver: Poorly planned infrastructure development	On-going	increasing	n.a.	Improved spatial planning prior to infrastructure development (zoning)
Underlying driver: Lack of Law enforcement				
Direct driver: Human-induced forest fires	On-going	continued	Medium source	Law enforcement Environmental education
Underlying driver: Environmental circumstances, geographic location				
Direct Driver: Natural disasters, e.g. cyclones, hurricanes and floods	On-going	continued		Implementation of climate change adaptation and mitigation strategies in relevant sectors Programs: Fiji National Adaptation Program for Action

Table 3: Drivers of deforestation in Fiji, estimated carbon impacts, and countermeasures[7].

1.4.2 Drivers of Forest Degradation

Forest degradation is difficult and costly to quantify as the loss of carbon stocks can only be measured through ground-based forest inventories. Fiji has made important first steps in establishing permanent sample plots (PSP) that will provide for a detailed analysis of degradation dynamics and progress is being made to quantify degradation through forest carbon inventories and improved satellite imagery. Categorizing drivers into deforestation and degradation is not always possible; some drivers of deforestation listed above may also cause degradation in some cases and complete forest conversion in others.

Despite the inclusion of RIL standards into the Fiji Forest Harvesting Code of Practice (2013), unsustainable commercial logging is still common practice, resulting in forest degradation and considerable damage to soils and waterways. A number of cases of illegal logging were reported in recent years, and although the majority were small-scale, illegal over-cutting and undeclared timber in licensed forest projects may be significant. Rehabilitation measures are rarely applied and silvicultural treatments of logged-over forests are widely unknown.

Driver	Current Situation (2000-2015)	Future Situation (2015-2030)	Carbon Impact	Initiatives to address driver
Commercial conventional logging	On-going Illegal logging reported to be mostly small-scale, but may be significant under the cover of licensed forest projects	More access roads – increased logging Logging trend may also decrease in natural forests considering the shift from logging to conservation and plantation forestry with incentives	Large source	Revision of Fiji Forest Harvesting Code of Practice to include RIL measures Project: Nakavu Sustainable Forest Management Pilot Site (FD).
Firewood collection	Increasing fuel wood collection for forests	Potentially decreasing as energy infrastructure is	Small source	

[7] Source: FCPF Readiness Preparation Proposal Fiji, 2014.

Driver	Current Situation (2000-2015)	Future Situation (2015-2030)	Carbon Impact	Initiatives to address driver
Continuous harvesting of mangroves in given area for firewood **Collection of non-timber forest products**	Escalating mangrove harvesting (firewood & construction)	being developed	(high impact on mangroves)	
Invasive species (weeds, pests & disease) **Succession of invasive species (domesticated cattle & pigs on free run)**	Increasing	Increasing	n.a.	Implementation of programs to control invasive (National Biodiversity Action Plan)
Fires cause forest degradation at edge of the forests (influenced by climate change)	Potentially decreasing as traditional livelihoods decline with urbanization	Potentially decreasing	Small source, mostly impacting plantations	Forest certification (Fiji Pine)

Table 4: Drivers of forest degradation in Fiji, estimated carbon impacts and countermeasures[8].

Alongside sawn timber for domestic use, forests are also a source of fuel wood for communities living in or around forests. Fuel wood is sourced from the fringes of forest near villages while construction timber is often harvested from easily accessible natural forest areas and pine woodlots. Charcoal continues to be used throughout the islands and is often made from mangroves. One tradition that causes significant forest degradation is the burning of forests for pig hunting and easy land clearance. In natural forests this normally affects forest edges, but which often burn out of control.

2 Methodology

In this study, a methodology is presented and applied to estimate carbon emissions from selective logging by means of activity-related emission factors relative to the cubic meter of felled timber. The methodology was originally conceived for one of the earliest forest-based carbon offset projects- the Noel Kempff Climate Action Project in Bolivia (Brown et al 2000). More recently, the same methodology was applied to estimate carbon emissions from forest degradation caused by selective logging in six tropical timber-producing countries (Pearson et. al, 2013). Based on the IPCC gain-loss approach, the losses in biomass carbon stock caused by logging activities are quantified using timber production data. This approach offers an uncomplicated and cost-efficient alternative to estimate emissions from selective logging at national level in the absence of reliable forest degradation data from forest inventories and satellite imagery. In Fiji, official timber production data is easily available and considered sufficiently reliable, as it represents the base for the calculation of landowner income and government fees and taxes.

[8] Source: FCPF Readiness Preparation Proposal Fiji, 2014.

2.1 Relevant Carbon Pools

The three main emitters in selective logging are the felled trees and associated timber waste, the felling damage to the residual stand and the installation of the logging infrastructure. The following carbon pools are eligible for the carbon estimations carried out:

Carbon Pool	Status	Justification
ABG trees >10cm	included	Expected to be highly relevant
BGB trees >10cm	included	Expected to be highly relevant
ABG+ BGB trees <10cm	not included	Not relevant. Biomass of small trees <10cm is not significantly influenced by selective logging (Mussong, 2014).
Deadwood	mainly included	Deadwood from timber waste (crowns, stumps) of felled trees expected to be relevant; Deadwood from trees killed and severely damaged by felling expected to be relevant; Small deadwood fraction not relevant, not significantly influenced by selective logging (Mussong, 2014).
Litter	not included	Not relevant. Biomass of small trees <10cm is not significantly influenced by selective logging (Mussong, 2014).
Soil	not included	Soil carbon is not expected to be significantly affected by selective logging
Logging Operations	not included	Lack of reliable data

Table 5: Relevant carbon pools for estimating carbon emissions from logging degradation in Fiji.

2.2 Emission Factor Calculation

The emission factors are calculated from the respective sums of emissions caused by the logging operations (tree felling and extraction, felling damage to residual stand, construction of logging infrastructure), each divided by the felling volume. The total emission factor is described by the following formula:

$$EM_{TOT} = EM_{FELL} + EM_{DAM} + EM_{INFR}$$

where:

EM_{TOT}: Total logging emission factor (in t C m^{-3});

EM_{FELL}: Emission factor felled trees (in t C m^{-3});

EM_{DAM}: Emission factor felling damage to the residual stand (in t C m^{-3});

EM_{INFR}: Emission factor logging infrastructure (in t C m^{-3}).

Emission Factor	Factor Components	Data Source
1. Felled trees (EM_{FELL})	1.1 Emissions from logs	Log records
	1.2 Emissions from timber waste from the felled trees (crown-, bole-, stump-, and below-ground biomass)	
2. Felling damage to the residual stand (EM_{DAM})	2.1 Emissions from killed (uprooted and snapped) trees >10cm (above and below-ground biomass)	Post-harvesting damage assessment
	2.2 Emissions from severe crown damage	
3. Logging infrastructure (EM_{INFR})	3.1 Emissions from the clearing of all trees >10cm (AGB+BGB) for logging road construction	GIS data logging infrastructure Pre-harvesting inventory
	3.2 Emissions from the clearing of all trees >10cm (AGB+BGB) for skid trail construction	
	3.3 Emissions from the clearing of all trees >10cm (AGB+BGB) for the construction of log landings	

Table 6: Description of emission factors from selective logging and their respective components.

2.3 Comparison of Emissions from Forest Degradation and Deforestation

2.3.1 Assumptions made for the Estimation of Emissions from Forest Degradation

1. The completely official log production from natural forests in Fiji currently originates from conventional logging. Conventional logging produces on average 13% more emissions than SFM at the same extraction rate;
2. The extraction rate under conventional logging is 50 m^3 ha^{-1}, which corresponds to a 2nd rotation conventional logging as demonstrated in the Nakavu SFM/REDD+ pilot site;
3. The logging emission factor that corresponds to conventional logging at the above-mentioned extraction rate is 1.1 tons C m^{-3};
4. The annual timber production from natural forests in Fiji is 62,500 m^3, which corresponds to the average annual log production (official figures) from 2004-2013 (see Table 11).

2.3.2 Assumptions made for the Estimation of Emissions from Deforestation

1. Current deforestation in Fiji occurs at the same rate as the average annual net deforestation from 2001-2007[9] (Table 10);
2. The carbon stock of the converted forest corresponds to the national average in natural forests of 67 tons C ha^{-1} [10];
3. The carbon stock of natural forest regrowth corresponds to the IPCC default value[11] for shrub land of 30 tons C ha^{-1}.

[9] Source: Forest Cover Change Analysis (SOPAC, 2012).
[10] Source: Fiji National Forest Carbon Assessment, 2011.
[11] Source: IPCC Guidelines for national GHG inventories, 2006.

2.4 Assumptions made for the REDD+ Scenario Conventional Logging to SFM

- **Baseline Scenario (Conventional Logging)**:
  - Same assumptions as for the estimation of logging degradation;
- **REDD+ Scenario (SFM):**
  - The areas under forest management are equal in the baseline and in the REDD+ scenario;
  - The extraction rate is reduced to 21 m^3 ha^{-1} (potential extraction rate under medium logging intensity in 2^{nd} rotation, as demonstrated from the Nakavu SFM / REDD+ pilot site);
  - The logging emission factor which corresponds to SFM at the given extraction rate is 0.9 tons C m^{-3}, which includes a 75% emission reduction of the logging infrastructure emissions due to the reuse of forest roads, skid trails and log landings in the second rotation.

2.5 Available Datasets

All carbon calculations in this study are based on forest inventory data and harvesting records from the Nakavu SFM / REDD+ pilot site (description see Appendix A). The models used to perform the carbon calculations are presented in Appendix B. The following datasets were used in this analysis:

- Pre-harvest inventory data, trees >10cm (1^{st} rotation);
- Log scaling records (1^{st} rotation);
- Post-harvesting-damage assessment (1^{st} rotation);
- 100% pre-harvest inventory data, trees> 35cm (2^{nd} rotation).

3 Emission Factors from Selective Logging

3.1 Key Logging Statistics

Logging system	Extraction rate	Felled trees	QMD felled tree	Mean log volume
	$m^3\ ha^{-1}$	$N\ ha^{-1}$	cm	m^3
SFM (heavy)	102	44	52.4	2.3
SFM (medium)	51	16	60.0	3.2
SFM (light)	21	7	61.8	3.1
CNV	59	35	47.8	1.7

Table 7: Key logging statistics from the SFM / REDD+ pilot site in Nakavu, Fiji.

The structure of Fiji's natural forests is characterized by an abundance of small-medium sized trees, which results in the removal of comparably high stem numbers, especially under heavy intensity SFM and conventional logging. Under SFM a pre-harvesting inventory using diameter limit tables (DLT) is carried out, which results in the selection and felling of more species and larger trees than under conventional logging (for further information on forest harvesting system, see Appendix A).

3.2 Emission Factor Analysis

Logging system	EM_{FELL}	EM_{DAM}	EM_{INFR}	EM_{TOT}
	$t\ C\ m^{-3}$			
SFM (heavy)	**0.56**	**0.05**	**0.15**	**0.76**
SFM (medium)	**0.56**	**0.15**	**0.20**	**0.92**
SFM (light)	**0.66**	**0.11**	**0.53**	**1.30**
CNV	**0.69**	**0.15**	**0.21**	**1.05**

Table 8: Emission factors from SFM and conventional logging in Fiji.

Felling Emission Factor EM_{FELL}

The logs and the associated timber waste account for the highest share of logging emissions, which for simplicity are assumed to be committed entirely at the time of the event. The percentage of felling emissions in relation to the total logging emissions ranges from 53% in light SFM to 65% in CNV and 74% in heavy SFM. The felling emission factor is very similar in medium and heavy SFM, but significantly higher in light SFM and CNV. In light SFM, this is caused by the comparably low extraction rate (by which the felling emissions are divided). In CNV, the reason lies in the accumulation of comparably high volumes of timber waste, resulting from the felling of a higher number of smaller trees.

Damage Emission Factor EM_{DAM}

The share of damage to the residual stand is surprisingly low, ranging from 7% of the logging emissions in heavy SFM to 16% in medium SFM and in CNV. This is caused by generally low numbers of severely damaged residual trees, which range from 3% in light SFM to 7% in heavy SFM and 9% in CNV. In comparison, selective logging has been shown to damage as much as 28-35% of the residual trees in RIL and 48-56% in conventional logging in tropical Asia (Sasaki & Putz, 2009). The low damage is most likely caused by the comparably small size of the harvested trees, in combination with the dense forest structure in Fiji, as compared to other managed tropical forests (see chapter 4).

Logging Infrastructure Emission Factor EM_{INFR}

Logging infrastructure accounts for 17 - 19% of the logging emissions in medium and heavy SFM, and for 40% in light SFM. Although heavy SFM causes the highest area of exposed soil (11%), it possesses the lowest relative emissions in this category. The relative emissions from logging infrastructure in the light SFM are about threefold of those in the other interventions and more than double of those in conventional logging. This is caused by the circumstance that in light SFM harvested trees are fewer in number but widely scattered, thereby requiring a comparably extensive skid trail network (8% exposed soil).

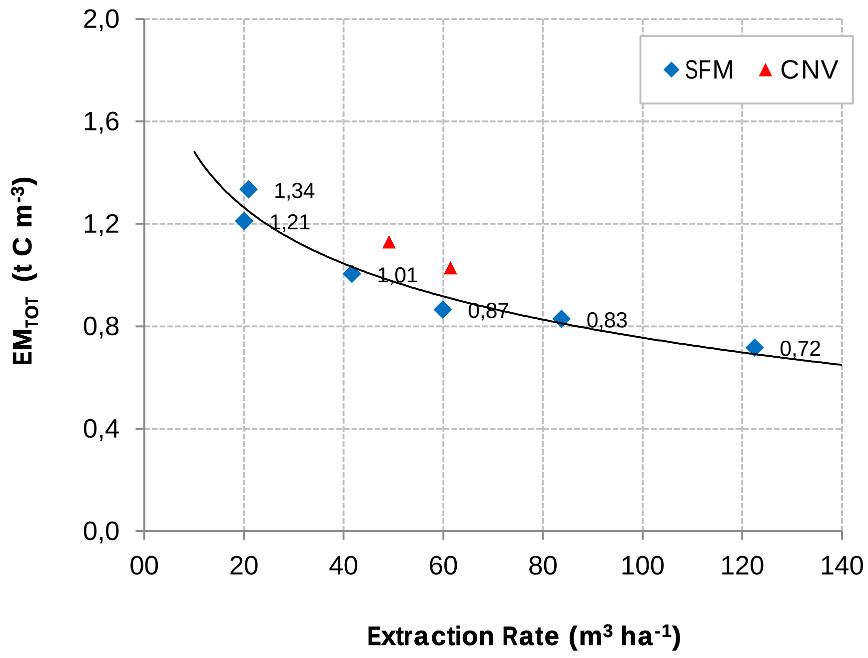

Figure 2: Correlation between the logging emission factor and the timber extraction rate.

Figure 2 displays the complete results of the emission factor from SFM and CNV in relation to the extraction rates (for details see Appendix C). Emission factors and extraction rate are negatively correlated: The higher the extraction rate, the lower are the relative emissions committed by each cubic meter of felled timber and vice versa. The emission factor from SFM can be estimated using the following logarithmic function:

$$EM_{TOT} = -0.316 * LN(VOL_{FELL}) + 2.21$$

Where:

EM_{TOT}= Total emissions from logging (t C m^{-3});

VOL_{FELL}= Extraction rate (m^3 ha^{-1}).

Under conventional logging, the emission factors are on average 13% higher than the predicted value at the same extraction rate under SFM. The data from conventional logging is not yet sufficient for a separate analysis and model development however.

4 Comparison of Logging Emission Factors in Fiji with Results from other Case Studies

Country	Extraction Rate	EM_{FELL}	EM_{DAM}	EM_{INFR}	EM_{TOT}
	$m^3\ ha^{-1}$	$t\ C\ m^{-3}$			
Fiji SFM (avg.)	54	0.57	0.10	0.22	0.89
Fiji (CNV)	59	0.69	0.15	0.21	1.05
RO Congo	9	0.25	0.50	0.24	0.99
Indonesia	34	0.25	0.57	0.67	1.49
Brazil	5	0.38	0.72	0.28	1.38

Table 9: Logging emission factors from Fiji compared to results from selective logging in tropical Africa, South East Asia and South America[12].

The emission factors from selective logging in Fiji are lower than but comparable in dimension to emission factors from similar studies in tropical in Africa, South East Asia and South America, which range from 0.99-1.49 t C m^{-3}. For better visualization, the data from Fiji in comparison with the other case studies is displayed in the scatter plot diagram below.

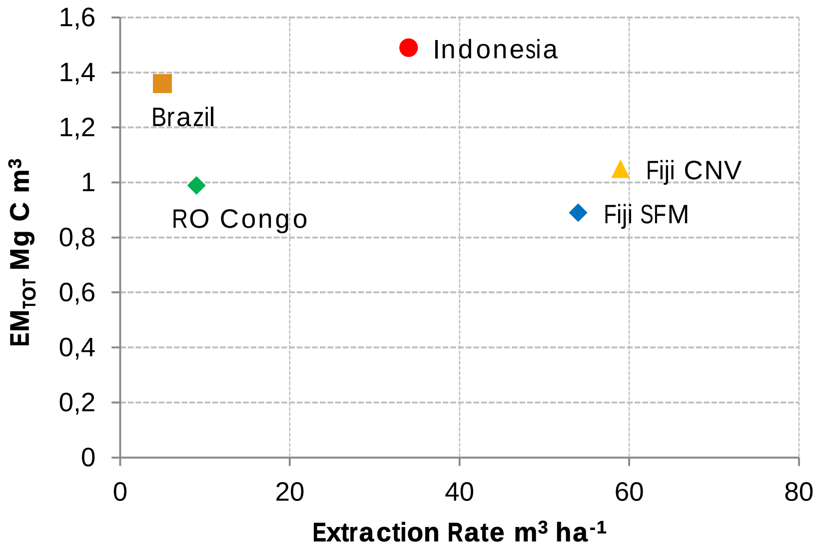

Figure 3: Scatter plot diagram demonstrating the relation between logging emission factors and the timber extraction rate in Fiji and other case studies.

Although comparable in dimension, there are important differences in the proportional distribution of the emission factor components between the results from Fiji and the compared case studies.

Firstly, the relative emissions from logs and timber waste are significantly higher in Fiji than in any of the other case studies. This can be explained by the following reasons:

- The logging intensity and number of extracted trees are higher in Fiji than in any of the compared studies;
- Below-ground biomass from the felled trees was included in this analysis, which may not be the case in the other case studies;

[12] Pearson et al (2013).

- Differences in data analyses may have led to different results: In this study, the above-and below-ground biomass was estimated using robust, but not site-specific models (see Appendix B), whereas in the compared studies the data was obtained through field measurements. The models used in this study may have led to an overestimation of the log and waste biomass of the felled trees.

Secondly, as already described in the previous chapter, the emissions from logging damage to the residual stand in Fiji are very low. The damage emissions are generally 3-5 times higher in all compared case studies. Several reasons could explain this circumstance, as explained below:

- At 56 cm, the mean diameter of the harvested tree in Fiji is rather small, as compared to 104 cm in the compared studies. Bigger trees generally have much bigger crown surfaces and therefore cause much more damage when felled than medium sized trees;
- A single-layer canopy and tree heights that rarely exceed 30 m without emergent trees characterize natural forests in Fiji. The interlinked crowns slow down the fall of the felled trees, which in turn reduces the damage to the residual stand. In the compared countries, the harvested trees can be expected to be mainly emergent trees with tree heights of 40 m and more. When felled, tall emergent trees develop immense kinetic energy, thus causing much more damage to the residual stand;
- The damage emissions will be underestimated in this study, because only trees suffering from severe damage (uprooted, snapped, severe crown damage) are included, whereas slight felling damage is neglected. However, some trees that are slightly damaged may subsequently die, and there are suggestions that this quantity may be as high as 8-10% of residual trees (Pinard & Putz, 1993);
- The data used to calculate the damage emissions derives from a post-harvesting damage assessment, which was carried out in limited number of PSP and without statistical analysis to quantify the uncertainty. Therefore, the sample size is probably not representative. In the future, the field data collection for post-harvesting assessments should be carried out in the felling gaps and with sufficient sampling size.

5 Emissions from Selective Logging compared to Emissions from Deforestation

The merging of logging emission factors and log production data reveals that the annual emissions from legal commercial logging in Fiji amount to 252,106 t CO_2. Fiji's National GHG[13] Inventory however reports much lower logging emissions of 74,700 t CO_2 per year. The latter were estimated using an IPCC Tier 1 methodology and are therefore expected to be less accurate than the results from this study.

	Total Area 2001-2007	Annual Area 2001-2007	Emissions
	ha	ha $year^{-1}$	t CO_2 $year^{-1}$
Deforestation Natural Forest	995	142	34,923
Regrowth Natural Forest	132	19	2,075
Net Deforestation	863	123	32,849

Table 10: Annual deforestation and associated carbon emissions in Fiji[14].

[13] Republic of Fiji Second National Communication to the UNFCCC, 2014
[14] Source: Forest Cover Change Analysis (SOPAC, 2012).

Official Log Production	Logging Emission Factor	Emissions from Sel. Logging	Emissions from Deforestation	Ratio
m^3 year^{-1}	t C m^{-3}	t CO_2 year^{-1}		
62.500[15]	1.1	252,106	32,849	7.7

Table 11: Emissions from logging degradation and deforestation in Fiji.

Deforestation rates in Fiji are minimal at forest cover losses of less than 0.1% per year, which results in emissions of 33,000 t CO_2. The deforestation rate presented in this study derives from SOPAC's 2012 forest cover change analysis, which currently represents the most comprehensive deforestation assessment conducted in Fiji. Other sources state different scenarios however: The FAO Forest Resource Assessment (2010), for example, reports natural forest net gains of approximately 7000 ha annually, while Fiji's second communication to the UNFCCC[16] reports net removals (negative emissions) of 6.8 Million t CO_2 of per year from natural forests. Under such circumstances, the ratio between degradation and deforestation would be significantly higher, but the general result, which confirms forest degradation as the most important source of emissions from the forest sector, remains unchanged. The differences between the results demonstrate the difficulty to accurately assess deforestation at national level. Especially natural forest regrowth is difficult to distinguish from other land cover classes (e.g. young pine plantations, shrub-or grassland) using remote sensing data.

The preliminary drivers-of-change assessment included in the FCPF Readiness Preparation Proposal for Fiji (R-PP) predicts mostly increased deforestation rates until 2030, mainly as a result of economic development. Fiji's development policy includes strategies for food security and increased agricultural exports, which lead to increased incentives regarding the commercialization of agriculture and dairy farming, thereby potentially putting more pressure on natural forests. Recreational infrastructure and housing developments are expected to continue to expand into coastal areas and mangrove forests. Population growth is an underlying driver of deforestation that will lead to an increase in land-use changes through the establishment of new formal and informal settlements.

Commercial logging is the most important driver of forest degradation and bears the most significant potential for emission reductions from natural forests. Although the new FFHCOP (2013) is in effect and includes RIL standards, over-cutting and unregulated logging are common practice, a trend that can be expected to continue until forest companies are equipped with the necessary technical capacities and harvesting regulations are enforced. On the other hand, the native log production has been on a continuous decline over the past 30 years- a trend that can be expected to continue due to the decreasing resources potential and economic attractiveness of natural forests, the expansion of forest plantations, and a paradigm shift from logging to conservation with compensation incentives (e.g. PES, REDD+). Economic development, the main underlying driver of deforestation, may contribute to mitigate some drivers of forest degradation: Energy infrastructure developments will potentially cause a decrease in fuelwood collection from natural forests and the harvesting of mangroves for charcoal, while urbanization may cause a decrease in human-induced forest fires.

Even though deforestation and forest degradation rates can currently be considered modest, Fiji has experienced significant forest loss and degradation in the past and needs to address and gain control over the responsible drivers. This can only be achieved through the implementation and empowerment of adequate laws and policies that harmonize economic development, land-use planning and sustainable resource utilization. Once in place, these will lead to reduced greenhouse gas emissions from forests while maintaining the multiple co-benefits provided by healthy forest ecosystems.

[15] Mean annual log production from natural forests in Fiji 2004-2013.
[16] Republic of Fiji Second National Communication to the UNFCCC, 2014

6 Contributions to the REDD+ Strategy Option "SFM and Forest Enhancement Activities"

The log production from natural forests in Fiji has been on a continuous decline over the past 30 years, which clearly demonstrates how unsustainable logging practice has led to degraded production forests, resulting in decreased income for the local and the national economy and losses of ecosystem services. In response, Fiji has developed policies and strategies to address the drivers of forest degradation: The Forest sector action plan outlines the transition to SFM as one of the main forest sector goals. The national REDD+ program is currently in the second phase and a national REDD+ strategy in development that will include SFM and forest enhancement options, accompanied by strategies aimed to improve forest governance and law enforcement. The new FFHCOP is in effect since 2013, which has been revised and amended to incorporate RIL standards. Fiji acknowledges however, that most of the above-mentioned strategies lack implementation and enforcement due to limited technical capacities and insufficient resources in the logging companies and the law enforcement agencies.

Currently, the entire log production from natural forests in Fiji originates from conventional, unregulated timber harvesting without adherence to the regulations of the FFHCOP. The REDD+ strategy option "SFM and forest enhancement activities" targets the implementation and enforcement of SFM practice in compliance with the FFHCOP. The REDD+ activities will create carbon benefits from avoided forest degradation, which will positively contribute to Fiji's emission balance from the forest sector, and generate non-carbon benefits resulting from healthier forest ecosystems.

From a silvicultural perspective, the most effective method to reduce emissions from selective logging is the reduction of the logging intensity, combined with the application of techniques to minimize the avoidable timber waste. Results in the present study demonstrate that 53-74% of the logging emissions in Fiji are a direct result of logs and the associated timber waste. Therefore, a reduction in the extraction rate will have the highest impact on the reduction of the overall logging emissions, as is displayed in Figure 4. One of the most important advancements in the new FFHCOP is the regulation of the allowable cut through the use of species-specific diameter limit tables (DLT), which provide three yield options: Heavy (40-60% volume removal), medium (20-40% volume removal) and light (10-20% volume removal) logging intensity.

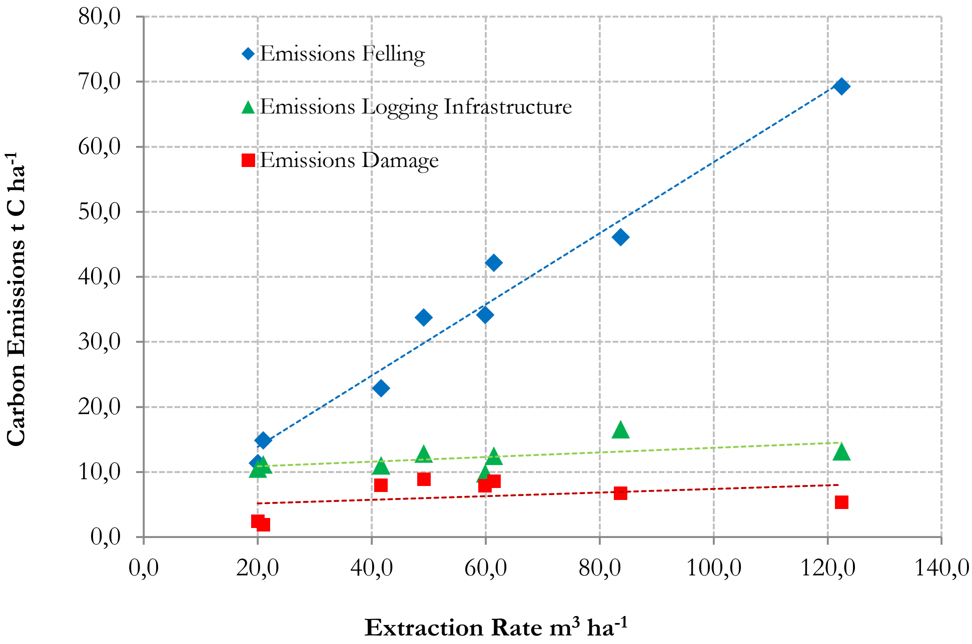

Figure 4: Proportion of per-ha emissions from felling, logging infrastructure and damage at different extraction rates.

Table 12 presents a simplified carbon calculation that simulates the transition from conventional logging to SFM practice at national level. The analysis is based on the combination of emission factor results and national log production data, as described in chapter 2.4.

	Conventional Logging	SFM
Component 1: Commercial Logging Information		
Extracted Volume (m^3 $year^{-1}$)	62,500	26,250
Extraction Rate (m^3 ha^{-1})	50	21
Log Volume Reduction (m^3 $year^{-1}$)	0	36,250
Component 2: Carbon Emissions		
Logging Emission Factor (t C m^{-3})	1.1	0.9
Emissions from Logging (t CO_2 $year^{-1}$)	252,106	86,633
Avoided Emissions from Logging (t CO_2 $year^{-1}$)	0	165,473

Table 12: Simulation of a jurisdictional REDD+ scenario, based on a transition from conventional logging to sustainable forest management.

The simulation gives insights into the emission reduction potential of the REDD-SFM strategy option and the possible implications for the forest sector in Fiji. The transition from conventional logging to SFM leads to avoided emissions of potentially 165,473 t CO_2 at national level. Additional carbon benefits will arise if illegal logging is reduced through increased law enforcement and surveillance, but the magnitude is difficult to estimate as they fall out of a legal framework. The carbon benefits from SFM will be significantly enhanced by associated co-benefits, especially the restoration of degraded forest ecosystems, the recovery of the forest resources potential and the maintenance or enhancement of ecosystem services like watershed /soil protection and biodiversity conservation. Even though the avoidable emissions are modest, for Fiji the transition to SFM with REDD+ compensation is more attractive from macro-economic and climate change perspectives and leads to more advantages for the involved stakeholders than conventional logging or total forest protection, as previous studies[17] have demonstrated.

Assuming that the forest area remains equal in the conventional logging and the SFM scenario, the reduction of the extraction rate under SFM will lead to a loss in the annual log production of 36,250 m^3, as displayed in Table 12. The resulting shortage in timber supply on the domestic market can be expected to provoke leakage, for example in form of increased illegal and small-scale logging activities, which in turn lead to the reversal of the achieved emission reductions. Therefore, strategies aimed at monitoring and preventing leakage need to be adopted concomitant to the implementation of SFM activities. Preventive strategies could involve the expansion of the natural forest area under SFM (i.e. through the establishment of new timber concessions), thereby increasing the supply of raw material on the market. Any expansion of the SFM area and the timber production will evidently decrease the avoided emissions- but the loss in carbon benefits is expected to be compensated by the multiple co-benefits arising from this strategy. The successful implementation of new timber concessions will require adequate forest management planning at national level, as well as the existence of sufficient forest resource potential, which may locally already be depleted- especially in easily accessible forest areas which have suffered prolonged overuse. In such areas, carbon stock enhancement activities like forest ecosystem restoration through silvicultural measures (enrichment planting, increasing growth rates of future crop trees) are recommendable. Additionally, reforestation activities in degraded areas as planned under the REDD+ strategy option "Expand tree plantations" should be implemented concomitant to SFM activities to increase the supply of plantation timber on the market and compensate for the reduction of timber from natural forests.

Among the most important elements towards the broad implementation of REDD-SFM activities on the ground is the establishment of functional forest governance structures such as forest surveillance procedures and a national forest information system. Such structures can ensure that selective logging is carried out in compliance with the regulations of the FFHCOP and reduce illegal, unregulated and inappropriate timber

[17] Mussong, 2014: Carbon emission factors of differently managed natural rainforests in Fiji

harvesting. A functional forest information system will furthermore directly benefit the National Forest Monitoring- (NFMS) system by providing comprehensive and up-to date forest management data and information. This will allow for the quantification of emissions and emission reductions associated with the transition to SFM, based on emission factors and forest management area- and timber production data, combined with periodic field verifications. This simple and cost-efficient method represents an approach that could limit the need for expensive terrestrial forest carbon stock inventories. For Fiji, this is an important issue considering the small size of the natural forest management area, the modest absolute scale of avoidable emissions from selective logging and the limited capacities of government forest agencies.

In this context, it is important to carry out further research on logging emission factors from SFM and conventional logging. The results in the present report derive from a first rotation harvest and are site-specific to the comparably well-stocked natural forest pilot site in Nakavu. In order to improve the reliability of emission estimations at national scale, it is important to broaden the data pool through continued and extended research regarding emission factors in second rotation harvesting and in other forest management projects and pilot sites. A continuation of the development of species-specific allometric equations from natural forests species is furthermore recommended to improve the accuracy of the logging emission factors.

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Appendices

Appendix A: Description of the Nakavu Forest Management Pilot Site (NFMPS)

Site Conditions

The NFMPS is located 9 km north-west of Navua, in the Namosi Province on Fiji's main island Viti Levu. It is covered with dense lowland forest and rugged terrain with frequent occurrence of steep slopes and an abundance of water courses. The annual precipitation is very high at more than 5000 mm, and is rather uniformly distributed throughout the year (de Vletter, 1991).

Area and Activity History

The NFMPS covers 309 ha and is owned by clans from the nearby Nakavu village. The area has a long tradition as a forest management research site. Since 1989, it is under lease by the Fijian Forestry Department and from 1989-1994, was selected as the pilot site for the development of a pioneer SFM concept for natural forests under the Fijian-German Forestry Project. A selective logging operation was carried out from 1992-1994 to compare the mid-term effects of SFM and conventional logging on forest structure and productivity. Today, the area is managed by the FD as a SFM/REDD+ pilot site to develop and test parameters for the integration of SFM and REDD+. Since 2012, the FD receives support from the BMUB-funded regional project "Climate Protection through Forest Conservation in Pacific Island Countries" through technical assistance in research projects and the continuation of the SFM demonstration activities. The second rotation harvesting in the NFMPS site was initiated in 2013 and is currently underway.

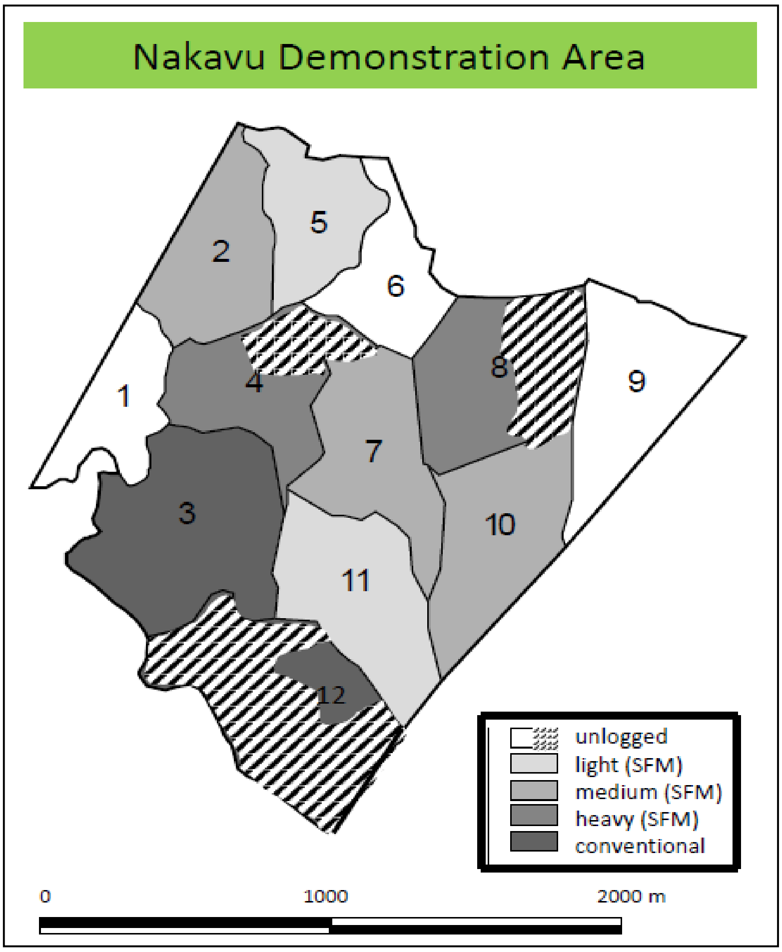

Figure 5: Map of NFMPS and compartment subdivision[18].

[18] Source: Mussong, 2014

Description of SFM and Conventional Logging demonstration activities

Prior to the first timber harvest from 1992-1994, the NFMPS was subdivided into 12 compartments (see Figure 5), to spatially organize the comparison of different harvesting treatments. 7 compartments were managed under SFM with different extraction rates, 2 were managed under conventional logging and 3 remained unlogged as control compartments. In the SFM treatments a pre-harvest inventory was carried out with the application of a species-specific diameter limit table (DLT), which had previously been developed under the NFMPP to regulate the harvesting intensity and achieve sustained yield of all harvested species. Other implemented SFM measures include the prior planning of logging roads and skid trails, the application of felling techniques to reduce damage to the residual stand, the installation of buffer zones and the enforcement of wet weather harvesting restrictions. In the conventional logging treatments, except for the observation of buffer zones, none of these measures were applied and all commercially valuable trees above the legal diameter limit of 35cm were harvested.

Logging system	Compartment No	Net Area Logged	Merchantable stock>35cm before logging	Extraction Rate
		ha	$m^3\ ha^{-1}$	
SFM (light)	5	17.9	137.4	20.0
	11	28.6	108.6	20.9
SFM (medium)	2	26.3	119.5	41.6
	7	28.9	145.7	59.9
SFM (heavy)	4	19.02	136.5	83.7
	8	17.17	199.8	122.5
Conventional logging	3	37.3	75.1	61.4
	12	10.42	63.9	49.1
Total		**185.6**	**120.7 (avg.)**	**55 (avg.)**

Table 13: Stand volume and extraction rate per compartment and per logging regime in the NFMPS.

Appendix B: Models and Parameters used in Carbon Calculations

Parameter	Model/Parameter	Source
Total tree height	-8.673797+8.378126*LN(DBH)	Mussong, 2012
Tree form factor	0.78	Unpublished data
Tree above-ground biomass	0.0509*DBH^2*Ht*WD	Chave et al., 2005
Wood density (weighted average in the NFMPS)	0.522	NFMPS Unpublished data
Tree below-ground biomass (individual trees)	EXP(-1.0587+0.8836*LN(AGB))	Cairns et al., 1997
Tree below-ground biomass (root-to-shoot ratio)	0.24	Cairns et al., 1997
Deadwood from broken crown branches	20% of the biomass of trees suffering from severe crown damage (crown breakage of 40% or more)	Preliminary estimation

Parameter	Model/Parameter	Source
Tree biomass to carbon conversion factor	0.5	IPCC, 2006
C to CO_2 conversion factor	3.667	

Table 14: Models and parameters used in the carbon calculations.

Where:

AGB= Above-ground biomass

BGB= Below-ground biomass

DBH= Diameter at breast height

Ht= Total tree height

WD= Wood density

Appendix C: Complete Emission Factor Results from all Logging Treatments

Treatment	Compartment Number	Extraction Rate	EM_{EXTR}	EM_{DAM}	EM_{INFR}	EM_{TOT}
Conventional logging	3	61.4	0.686	0.141	0.203	1.030
	12	49.1	0.687	0.181	0.262	1.130
SFM heavy	4	83.7	0.551	0.081	0.198	0.830
	8	122.5	0.566	0.044	0.108	0.717
SFM medium	2	41.6	0.549	0.191	0.265	1.005
	7	59.9	0.570	0.132	0.164	0.866
SFM light	5	20.0	0.566	0.119	0.527	1.212
	11	20.9	0.709	0.092	0.534	1.335

Table 15: Results of the emission factor analysis (separate for all logging regimes).