Setup-scale Method for Field Carbon Monitoring of Logging Emissions at PNGFA-JICA Project Pilot Sites

Version 0.2

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PNG Forest Authority

JICA-PNGFA Project

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List of acronyms

AD	Activity Data
AFOLU	Agriculture Forestry And Land Uses
AGB	Above-Ground Biomass
ALP	Annual Logging Plan
BCEF	Biomass Conversion and Expansion factor for conversion in merchantable volume to total biomass (tonnes dry matter per m3)
BEF	Biomass Expansion Factor
BGB	Below-Ground Biomass
BLe	Baseline emissions
BUR	Biannually Updated Report
CF	Carbon Fraction of dry matter (tC/t.d.m.)
CO2e	Carbon Dioxide equivalent
D	Log diameter
dbh	Diameter at Breast Height
EF	Emission Factor
ER	Emissions Reductions
ERPD	Emission Reduction Programme Document
FELL	Biomass loss due to felling per setup area
FRL	Forest Reference Level
GHG	Greenhouse Gas
GIS	Geography Information System

GPS	Global Positioning System
h	Tree height
HAUL	Biomass loss due to hauling per setup area
IPCC	Intergovernmental Panel on Climate Change
L	Log length
LCOP	Logging Code Of Practices
MM	Man Month
NFI	National Forest Inventory
PNG	Papua New Guinea
PNGFA	Papua New Guinea Forest Authority
PRe	Project Emissions
R	ratio of below-ground biomass to above-ground biomass
REDD+	Reduction of Emissions due to Deforestation and forest Degradation and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks
RIL	Reduced-Impact Logging
RIL-C	Reduced-impact logging for climate mitigation refers to the set of RIL practices, and practices not included in RIL standards, that are defined by measurable thresholds and that can be verified by a carbon accounting methodology
RS	Remote Sensing
SKID	Biomass loss due to skidding per setup area
tC	tonnes of carbon
WD	Wood Density
WI	Winrock International

1. Summary Description

Papua New Guinea (PNG) is recognized for its vast tropical forests, playing a critical role in global carbon sequestration. However, commercial logging has led to significant forest degradation, making accurate carbon monitoring essential for environmental sustainability. The National Forest Management System (NFMS) currently relies on remote sensing and ground-based inventories to track changes in forest cover. While remote sensing is effective for large-scale deforestation detection, it struggles to capture fine-scale degradation from selective logging, including skid tracks and felling gaps. Therefore, this methodology bridges that gap by providing a systematic approach to quantifying biomass loss from logging operations.

This method is designed to be applicable at the "setup" scale, the smallest operational unit in logging concessions, enabling high-resolution monitoring. By measuring biomass loss due to logging activities—including felling, skidding, and hauling infrastructure—this methodology ensures comprehensive assessment and comparison with improved logging practices such as Reduced Impact Logging (RIL). The methodology is divided into two major parts: the quantification of logging-associated emissions and the comparison of logging impact performance. The first part focuses on collecting direct field data on emission sources, while the second part gives guidance to assess the effectiveness of improved logging practices in terms of emission reduction.

To ensure accuracy, the methodology follows the Gain-Loss Method recommended by the IPCC. It integrates the Volume Method for estimating activity data (AD) and the Gain-Loss Method for deriving emission factors (EF). Allometric equation from Chave et al. (2014) is applied to estimate tree biomass based on field measurements of diameter at breast height (DBH) and tree height, while PNG's NFI adopted equations like Brereton Formula is applied for biomass and carbon calculation of logs, deadwoods, and stumps.

The method also includes simple procedures for field measurements and carbon loss calculation, as detailed out at attached Project Manuals. Skidding operations are assessed through sample skid track networks, where track lengths, widths, and collateral damaged deadwood are recorded. Felling damage is quantified by measuring logging residues such as stumps, top logs, and abandoned logs. Hauling infrastructure impact is estimated by measuring logging road widths and length, as well as log landing areas. Additionally, natural vegetation assessment at unlogged area provides a baseline carbon stock density which is applied for calculation of forest clearance caused by construction of logging infrastrutcures.

Baseline emission calculations rely on historical logging data, typically covering a 10-year reference period, to establish expected emissions under conventional logging. By comparing this baseline with emissions from improved logging techniques, the methodology enables the quantification of emission reductions, supporting participation in carbon credit markets.

2. Introduction

Papua New Guinea (PNG) is well known as the country where one of the largest rain forest areas and its richest biodiversity remained in the world. At the same time, forestry remains a key industry, significantly contributing to PNG's economy and rural development. According to PNG's reports submitted to UNFCCC (Forest Reference Level (FRL) and National REDD+ Strategy (NRS)), PNG still keeps forest covering 78% of the country but large percentage of forest area has been degraded by commercial logging and it is actually the largest GHG emission source in PNG. Therefore, accurate monitoring and assessment of forest degradation and associated emissions are particularly essential for achieving PNG National Determined Contribution (NDC) target. It also plays a critical role in regulating the environmental impact of logging and sustaining forest resources.

According to the Second National REDD+ Forest Reference Level of Government of PNG (2023), PNG's National Forest Management System (NFMS) adopted a combination of remote sensing and ground-based forest carbon inventory approaches. These approaches help determine forest cover, land-use and land-use change, and associated carbon stocks. For forest degradation caused by commercial loggings, remote sensing data is fully utilized to assess the presence of logging roads and other logging related infrastructures, as well as forest cover losses within accessible distance from those roads. The emission factor (EF) of forest degradation corresponds to the carbon stock change from primary forests to degraded forests, which inevitably includes not only the logging but also other degradations activities such as gardening, fire, fuel wood collection. Further, there is a certain limitation of remote sensing (RS) technologies to extract solely the actual direct impact caused by the commercial logging. In particular, detection of logging skid tracks under the canopy as well as felling gaps developed by felling activities is not at satisfactory level. Therefore, there is a strong necessity to develop alternative but solid methodology for assessing carbon emissions caused by logging operations.

Although there is no PNG's specific methodology to monitor logging-associated emissions specifically, the Verified Carbon Standard (VCS)'s methodology, namely *"VM0035: Methodology for Improved Forest Management through Reduced Impact Logging"*, is available and could serve to meet this demand. Reduced Impact Logging (RIL), defined as "the intensively planned and carefully controlled implementation of timber harvesting operations to minimize the environmental impact on forest stands and soils (ITTO, 2017)", requires monitoring and assessment of direct impact of logging operation in terms of biomass loss, comparing with conventional logging practices. RIL contributes to climate change mitigation by reducing avoidable biomass loss through improved logging operations. The

VM0035 methodology has been applied to the East Kalimantan Jurisdictional Emission Reductions Program in Indonesia, funded by the World Bank's Forest Carbon Partnership Facility (FCPF) Carbon Fund, along with its module titled *'VMD0047 Performance Method for Reduced Impact Logging in East and North Kalimantan'*.

The key condition of this methodology is that implementation of RIL practices does not intend a deliberate reduction in harvesting volume, making it a favorable criterion for PNG's context. Using this internationally certified methodology as a foundation, the JICA-PNGFA Project and PNGFA has developed a simplified method and associated procedures, in order to assess logging emissions at the setup level, referring to the regulatory context of PNG. Under this method, the priority is given to not only the logging infrastructure (hauling road, skid tracks), but also the carbon loss from tree biomass waste and damage associated with timber extraction. This corresponds to logging efficiency and is complementary to logging intensity/extent more related to production levels (harvested volumes or logged areas). Since this method could allow to quantify emissions from "conventional forest management" (commercial selective loggings in case of PNG) and distinguish between forest degradation due to commercial logging and other kind of forest degradation, GoPNG/PNGFA could not only advance FRL but also broaden its scope to include further REDD+ activities, such as sustainable management of forests through implementation of RIL practices, in near future, which would open new opportunities for carbon financing.

For smooth execution of this method, this document is comprised of two sections as follows. For further details procedures, please refer to two project manuals attached, which provides step-by-step guidance for field measurements as well as carbon loss calculations.

PART I: QUANTIFICATION OF LOGGING-ASSOCIATED EMISSIONS

PART II: COMPARISON OF LOGGING IMPACT PERFORMANCE

PART I: QUANTIFICATION OF LOGGING-ASSOCIATED EMISSIONS

3. Target Carbon Pools, Scale, and Measurement Parameters

The carbon pools targeted under this method for carbon monitoring should be restricted to above- and below-ground tree biomass, as discussed in the below table, and therefore non-tree species like ferns, liana, palm, pandanus, bamboos, litters will not be accounted.

Carbon Pools	Included/Excluded	Remarks
Above-ground tree biomass carbon	Included	Significant pool affected by logging operation
Below-ground tree biomass carbon	Included	Significant pool affected by logging operation
Above-ground non-tree biomass carbon	Excluded	Non-trees like ferns, liana, palm, pandanus, bamboos, seedlings would be conservatively exluded
Deadwood biomass carbon	Included	Standing and lying deadwood produced by harvesting are included. Changes in stock of pre-existing deadwood are conservatively ignored.
Litter	Excluded	No significant change is expected
Soil	Excluded	No significant change is expected

Table 3-1: Target Carbon Pools

As defied by VM0035, aboveground carbon stocks include both live and dead (standing and lying) pools, and emission reductions quantified for the aboveground carbon pool represent transfer of biomass carbon from live trees to dead wood, followed by steady emissions via decomposition, without explicitly separating the accounting of these elements, as described in the below figure.

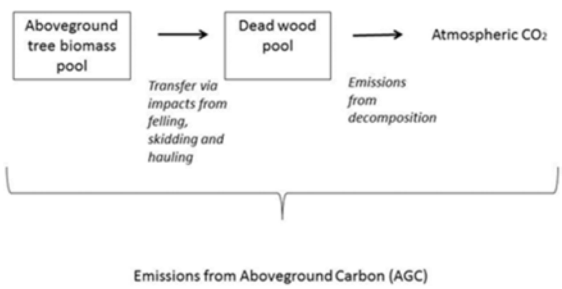

Figure 3-3: Schematic of Pools and Fluxes Incorporated in AGC Emissions (Source: VM0035)

In order to assess the logging-caused changes of target carbon pools in a practical manner, this method defined that the scale of field carbon monitroing survey is the smallest operation unit of logging concession, which is “Setup”, as illustrated in the figure below.

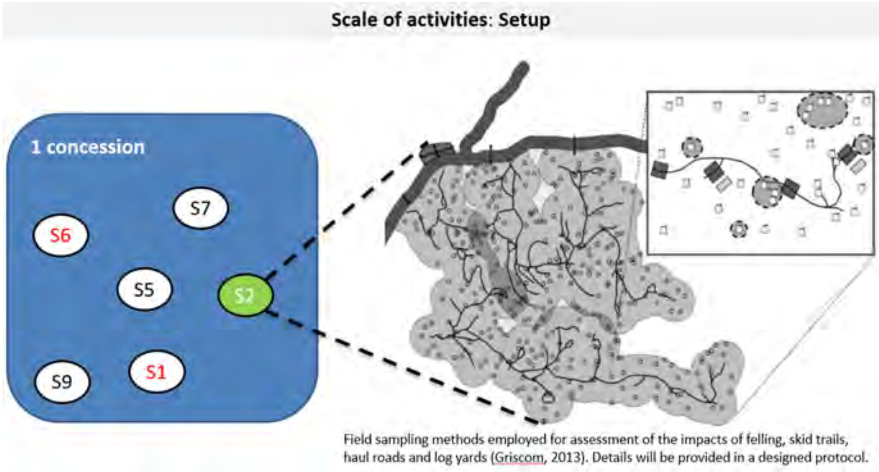

Figure 3-2: Scale of Field Carbon Monitoring

The method also accounts for an exhaustive list of emission sources identified in the field of logging operations, as presented in the figure 3-3, and the survey items listed in the table 3-1 need be covered during field carbon monitoring, in order to assess respective emissions.

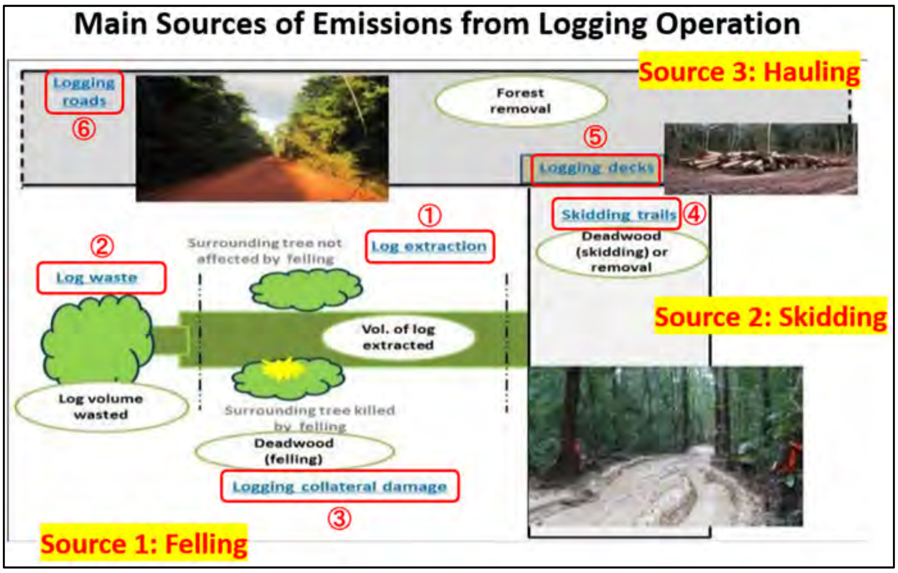

Figure 3-3: Emission Sources of Logging Operation

Emission Category	***Survey Items***
SKID	**Skid Track Area** at target setup
	(total length of both main and spur roads and average width)
	Skidding-caused Collateral Damage Impact at target setup
	(deadwood density per meter and total length)
	Natural Vegetation Carbon Stock Density
	(average carbon volume of natural vegetation per hectare)
FELL	**Felling-caused Damage Impact Density (Collateral Damage + Waste)** at target setup
	(deadwood and residue density per stump/tree and total number of tree felled)
	Log Extraction Impact of target setup
	(log extraction volume)
HAUL	**Hauling Road Area** at target setup
	(average width and length allocated for target setup)
	Total Log Landing Area at target setup
	(length and width of respective log landings)
	Natural Vegetation Carbon Stock Density
	(average carbon volume of natural vegetation per hectare)

Table 3-1: Field Carbon Monitoring Survey Items

For specific measurement objects as well as parameters are summarized in the below table. It should be noted that snapped trees above the first branch as well as logging camps will be not accounted under this method, as in case of the former, its mortality rate is less than 100%, while the latter will be considered once concession-level emission to be assessed (one or two camps would be expected at concession level).

Sources of emissions					**Measurement objects**	**Measurement values**
Forest carbon stock damage from selective logging	Carbon stock damage in logging gaps due to tree felling	Timber-trees	Log volumes	Extracted log volumes	Lying/removed deadwood	Length (L), Diameters of top and bottom of logs (D1-D4)
				Non extracted log volumes: trimmed, abandoned, forgotten	Lying deadwood in logs	Length (L), Diameters of top and bottom of logs (D1-D4)
			Non log volumes	Stumps	Stump	Height (H), Diameters of stump (D1-D2)
				Tops, Head logs	Lying deadwood	Length (L), Diameters of head logs/tops (D1-D2)
		Other trees	Uprooted volumes		Lying deadwood (G)	Length (L), Diameters of uprooted trees (D1-D2)
			Snapped trees	Above the first branch	live tree (mortality<100%)	**Not accounted here**
				Below the first branch	Standing deadwood (S)	Height (H), DBH
	Area Damaged due to log extraction	Skid trails			Standing deadwood (S)	Height (H), DBH
					Lying deadwood (G)	Length (L), Diameters lying deadwood (D1-D2)
					Area removed	Skid trail width, length, area
		Log landings			Area removed	Landing width, length, area
		Haul logging roads			Area removed	Haul road width, length, area
		Others such as camps etc.			Area removed	**Not accounted here**

Table 3-2: Measurement Objects and Parameters

4. Theory and Equations for Carbon Calculation

Emissions from forestry sector are calculated by deriving activity data (magnitude of human activity resulting in emissions or removals) and emission factors representing the change in carbon stocks as a result of the activity (IPCC's AFOLU guidelines, 2006).

Net emissions (Em) = Activity Data (AD) x Emission Factor (EF)

In terms of logging emissions, PNG has adopted the methodology of Remote-sensing method for Activity Data (AD) and Stock-change method for Emission Factor (EF) to estimate logging impact on forest carbon for Forest Reference Level Assessment, following IPCC's guidance. Under this methodology, EF of forest degradation corresponds to the carbon stock change from primary forests to degraded forests, which inevitably includes not only the logging but also other degradations activities such as gardening, fire, fuel wood collection. To address this limitation, this method adopted another IPCC recommended methodology, which is the combination of timber extraction rates (Volume Method) for AD and Gain-loss Method for EF, with focus on biomass loss.

Net emissions	=	Activity Data	x	Emission Factor
Emissions from industrial timber production tCO2e		Extracted volumes m3		Biomass loss associated to timber extraction activities tCO2e/m3

Figure 4-1: Logging Emission Calculation based on IPCC guidelines.

The Gain-Loss Method is designed to provide emission factor for all sources of emission as a function of the unit of timber production (ton of carbon per cubic meter extracted), as follows:

Total Carbon Emission (TCE) = Extracted Log Emission (ELE) + Logging Damage Emission (LDE) + Logging Infrastructure Emission (LIE)

TCE is the total loss of live biomass caused by immediate damage that occurs during operations. ELE (Extracted Log Emission) corresponds to extracted volume of the selected merchantable trees, which can be confirmed from the official record of Log Scaling. LDE (Logging Damage Emission) accounts for a log-related biomass left behind in felling gaps and incidental damage to surrounding trees. LIE (Logging Infrastructure Emission) accounts for removed biomass caused by infrastructures for skidding and hauling operation, including log landings. It should be noted that it is acknowledged that natural regeneration (Gain) would commence soon after logging operation is undertaken, and Gain-Loss method allows inclusion of such gains. However, gains from regeneration would NOT be counted under this method as the goal is to quantify total logging emission, avoiding offsetting immediate carbon loss caused by logging operation.

In order to calculate respective emission volumes, values listed in the table below will be required. Once TCE, or total volume of carbon loss caused by logging operation, is calculated by adding ELE, LDE and LIE, the value of EF can be calculated by dividing TCE with total log volume extracted again.

Emission Factor		Required Values
Logging Infrastructure Emission	Forest Clearance for Hauling Road	Total Hauling Road Area (ha)
		Natural Vegetation Carbon Stock Density (tC/ha)
	Forest Clearance for Log Landing	Total Log Landing Area (ha)
		Natural Vegetation Carbon Stock Density (tC/ha)
	Forest Clearance for Skid Track	Total Skid Track Area (ha)
		Natural Vegetation Carbon Stock Density (tC/ha)
Logging Damage Emission	Skidding-caused Collateral Damage	Total Skid Track Length (m)
		Average Deadwood Carbon Dencity per Skid Track Meter (tC/m)
	Felling-caused Collateral Damage	Recorded Number of Felled Trees (stump)
		Average Deadwood Carbon Density per Felled Trees (tC/stump)
	Log Wastes/Residues	Recorded Number of Felled Trees (stump)
		Average Log Waste Carbon Density per Felled Trees (tC/stump)
Log Extraction Emission	Log Extraction	Recorded Removed Log Carbon Volume (tC) (from Log Scaling Data)

Figure 4-2: Required Values for Emission Calculation

For carbon loss calculation, the methodological concept is adopted from IPCC, which is the equation for the annual carbon loss in biomass from wood removal due to harvesting. PNG's NFI default dry wood density factors by genus/species is utilized for this calculation, while IPCC's default values for carbon fraction (0.47) and root-shoot ratio (0.37) are also adopted by this method. On the other hand, IPCC's Biomass Expansion Factor (BEF) will not be applied under this method, as specific allometric equation for tree biomass estimation is adopted instead in order to avoid overestimation and reduce bias[1].

$L_{wood-removals}$ = Removed wood volume (V) x Biomass Expansion Factor (BEF) x Wood Density (WD) x (1+ Ratio of below-ground biomass (R))

[1] Gibbs, H. K. et. al., (2007). *Monitoring and estimating tropical forest carbon stocks: making REDD a reality*. Environmental Research Letters, 2(4), 045023. Also see West, T. A. P., et al. (2019). *Sustainable logging as a bridge between conventional timber extraction and climate-adaptive interventions*. Current Biology, 29(15), R700-R707

x Carbon Fraction (CF)

For tree carbon calculation, an allometric equation developed by Chave et al. (2014) is adopted, instead of applying BEF, same as PNG NFI methodology.

$$\textbf{Tree carbon} = \{0.0000673 \times (DBH^2 \times \text{Tree Height})^{0.976}\} \times WD \times (1+R) \times CF$$

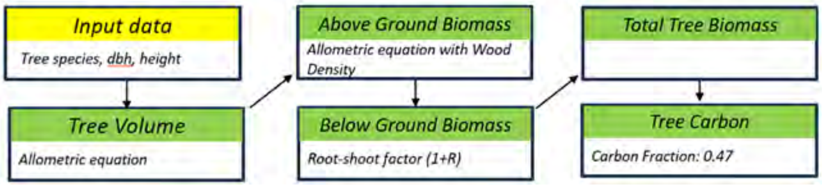

Figure 4-3: Process of Tree Carbon Calculation

In case of carbon volume of logs extracted, since log volume (m^3) is calculated at log scaling process, applying Brereton Formula, its carbon volume (tC) can be calculated through multiplying volume and wood density of species, as well as default value of carbon fraction, as follows.

$$\textbf{Extracted log carbon} = \{\pi(pi=3.141592)/40000 \times (\text{average of Diameters})^2 \times \text{Log length}\} \times WD \times CF$$

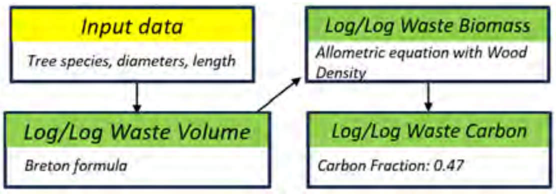

Figure 4-4: Process of Log Carbon Calculation

Additionally, combining equations adopted by PNG NFI methodology, stump carbon can be calculated from top-stump diameter and stump height, while Brereton formula adopted by PNG Log Scaling Guideline is applied for log residues' carbon calculation. Since estimation of removed log volume can be done based on available measurements from stumps and other residues, carbon loss caused by felling is calculated based on volumes (including estimated log volume), wood density, and carbon fraction value, applying following equations.

$$\textbf{Stump carbon} = \pi(pi=3.141592)/40000 \times (\text{Stump Top Diameter}^2 + \{(\text{Stump Top Diameter}+(0.00173*(130-\text{Stump height}) \times \text{Stump Top Diameter})/0.77510)\} \times WD \times (1+R) \times CF$$

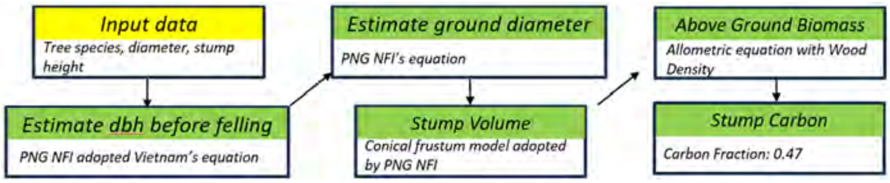

Figure 4-5: Process of Stump Carbon Calculation

Log residue carbon = {π(pi=3.141592)/40000 x (average of Diameters)^2 x Log length} x WD x CF

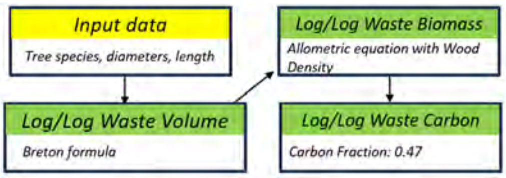

Figure 4-6: Process of Log Waste Carbon Calculation (same as log)

In terms of collateral damaged deadwood, there would be three different types: uprooted full-tree-form lying deadwood, broken lying deadwood, and standing deadwood snapped below the first branch (in case of snapped above the first branch will be excluded due to its survival rate, as illustrated in figure 4-7).

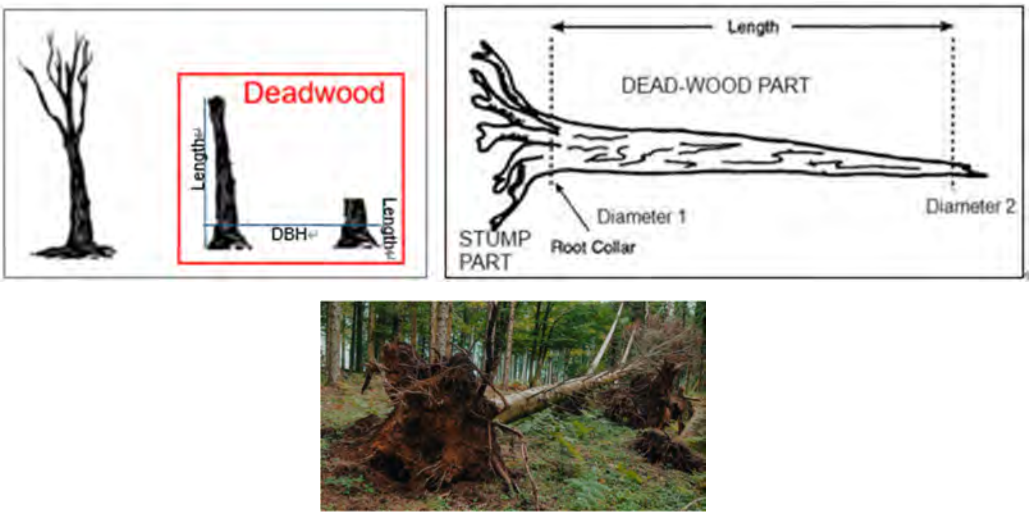

Figure 4-7: Deadwood (Photo: Full-tree-form lying deadwood)

In case of uprooted lying deadwood which keeps full form of trees with roots and top branches, the abovementioned allometric equation for tree carbon calculation will be applied and its biomass and carbon will be calculated based on DBH, Length, and Tree Species-specific wood density. On the other hand, biomass and carbon of lying deadwood with broken trunk, but without either roots or top branches, will be calculated based on root collar diameter, top-end diameter, length and species-specific wood density (Brereton formula will be applied for volume calculation like log and log pieces). In case of standing deadwood, same as lying deadwood, Brereton formula and PNG's wood density will be applied for estimating its volume.

5. Survey Method and Plot Designs for Field Measurement

This method adopted sampling-based assessment and also prioritize direct field measurements, following IPCC (2006) guidelines and VM0035, using both manual measurement tools (tape measure, diameter tape, clinometer) and devices like GPS. The followng is the summary of narrative survey method applied for field survey. For further details, please refer to attached project manuals.

<Skidding>

- **Skid Track Network**: Ramdonly selected 2-3 networks, accounted for approximately 35ha, should be sampled.
- **Skid Track Length**: Both main track and branches/spur roads should be measured by both GPS and tape measure.
- **Skid Track Width**: At least 6 widths (2 widths at every 100m) of main track should be measured.
- **Skidding Damage**: Skid Plots of 10m x (Skid track width + 10m) should be established on the main track at every 100m (see the following plot design), while measuring deadwoods killed by skidding operation (all deadwoods above 20cm DBH).

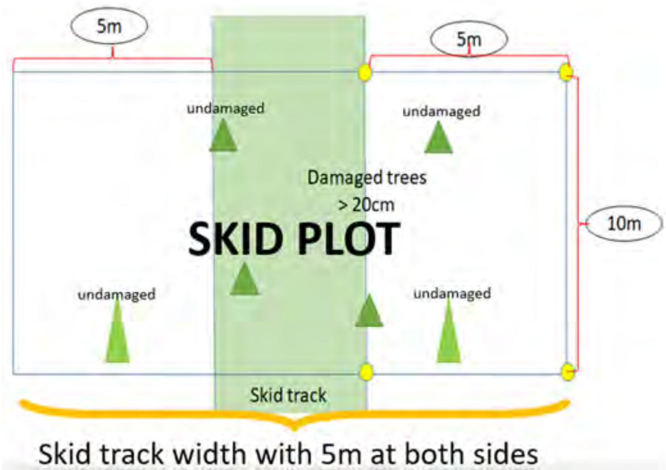

Figure 5-1: Skid Plot Design

<Felling>

- **Felling Damage:**
  - 2-3 Felling gaps, where the canopy is open due to tree felling (see the below photo), adjacent to respective Skid Plots should be identified, based on location of stumps.

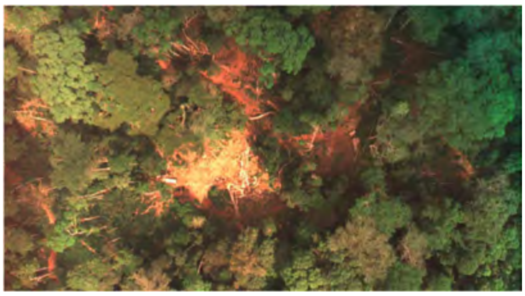

Figure 5-2: Felling Gap

  - Taking measurements of all log residues (stump, top log, remaining log piece, abandoned log) and deadwoods.

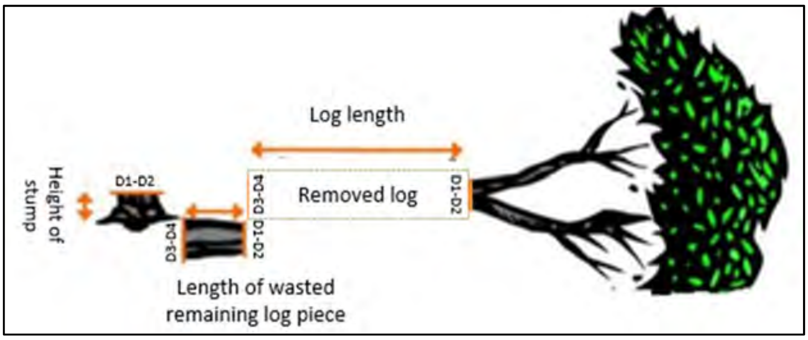

Figure 5-3: Log Residues

<Hauling>

- **Hauling Road Length**: Sample hauling road length should be identified from the location of two adjacent setups, and the length between the end of two, as illustrated in the figure below, should be measured with GPS (the total length will be divided by three setups).

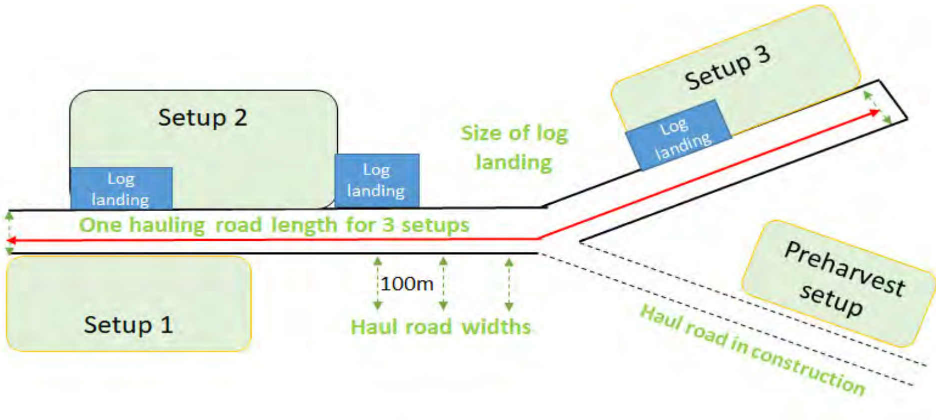

Figure 5-4: Sampling length of hauling road

- **Hauling Road Width**: Road widths at every 10% of road length should be measured with tape measures.
- **Log Landing Area**: Length and width of all log landings located in sampled setup should be measured, or alternatively measuring four sides of log landings with GPS.

<Natural Vegetation>

- Sample unlogged forest area should be identified by logging company.
- 100m strip-line based rectangular survey plot (30m x 100m) should be established, as illustrated below.

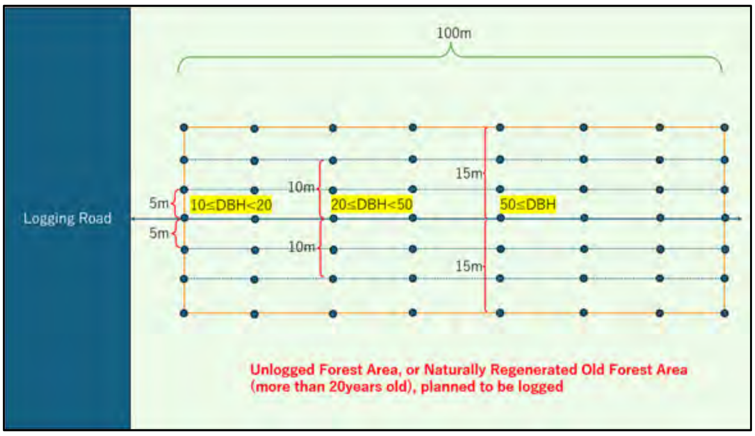

Figure 5-5: Natural Vegetation Survey Plot Design

- Inventory work should be conducted, measuring all trees above 10cm DBH, according to following thresholds, as described in the below table, while the height of every 4th trees as well as all trees above 40cm DBH should be measured.

DBH class based thresholds	Range from Strip-line/centerline	Plot Size
1) 10cm ≤DBH< 20cm	5m each side (total 10m)	0.1ha

2) 20cm ≤DBH< 50cm	10m each side (total 20m)	0.2ha
3) 50cm ≤DBH	15m each side (total 30m)	0.3ha

Figure 5-6: Threshold for Inventory

In case that field carbon monitoring to be conducted at a concession on naturally regenerated forests, potential restored carbon stock could be assessed based on actual years of forest regrowth after selective logging operation conducted in the past, as investigated and proved by Fox et al (2011)[2]. In case that the previous harvesting was occurred more than 20 years ago, full biomass is assumed to be recovered in disturbed forests, while estimated biomass recovered can be calculated based on Fox's equation in case of less than 20 years (please refer to the literature for further details).

To enhance data accuracy and reliability, this method strongly recommends to includes robust Quality Assurance and Quality Control (QA/QC) measures, as part of field carbon monitoring program. These include independent field audits by separate QA/QC team, data cross-validation with remote sensing.

6. Step-by-step Guidance

In order to execute field carbon monitoring of logging emission in a smooth manner, attached 2 project manuals are prepared by JICA-PNGFA Project, as step-by-step guidance, which provide procedual steps for both field carbon measurements as well as logging carbon emission calculations. Please refer to both project manuals to carry out this assignment.

[2] Fox J.C., Keenan R.J., Brack C.L. and Saulei S. (eds) 2011. Native forest management in Papua New Guinea: advances in assessment, modelling and decision-making. ACIAR Proceedings No. 135. Australian Centre for International Agricultural Research: Canberra. 201 pp.

PART II: COMPARISON OF LOGGING IMPACT PERFORMANCE

7. Baseline Setting

Emission factors integrate production data while incorporating temporal baselines to estimate gross emissions. For any given year with available production data – such as logged area or harvested volume – historical annual emissions can be retrospectively estimated. Analyzing historical emissions enables the identification of trends and the calculation of an annual average, which serves as the baseline. In this context, the baseline refers to the annual average carbon emissions from tree biomass within the designated setup area.

A baseline can be established to facilitate the estimation of emission reductions. Estimating business-as-usual (BAU) emissions involves extrapolating trends observed during the past reference period of a minimum of 10 years. Since harvesting within a setup occurs only once, unless awaiting the next rotation cycle, the setup scale is not suitable for repeated logging operations. This method therefore adopts the concession scale to establish a baseline for carbon performance assessment.

As for calculation of the baseline of specific concession where sampled setups for field carbon monitoring are located, this method adopted generic methodologies of IPCC (2006) guideline, as following equation.

BLe for logging actvities = Logging AD x Logging EF

As highlighted above, the baseline emissions (*BLe*) in tonnes of CO2 equivalent per year will be set based on reference period of 10 years. The 10-year reference period is aligned with international best practices for setting forest reference levels (FRL) in REDD+ methodologies defined by IPCC and UNFCCC. A decade-long timeframe allows for capturing natural variability in logging activities, including fluctuations in timber demand, policy changes, and forest management practices[3]. The activity data *(AD)* relating to logging intensity could be logging area (ha) or timber production volume (m3) per year, while Emission factor (*EF*) for logging operation in tonnes of CO2 equivalent emissions should be per unit of AD (tC/ha or tC/m3).

Regarding AD, either 1) "*Area of managed forest*" to be estimated based on Annual Logging Plans or RS time series data of logged over area, or 2) IPCC (2006) recommended *"Timber*

[3] Pelletier. J. et al. (2018), *Carbon emissions from selective logging in tropical forests: an assessment based on long-term field measurements in Panama*. Global Change Biology, 24(11), 5367-5379. Also, see Blanc, L. et al. (2019), *Long-term impacts of logging on carbon stocks in a Central African forest*. Environmental Research Letters, 14(9), 095007.

Volume" to be calculated based on official records of PNGFA, can be adopted. It should be noted that, according to the prior assessment of uncertainty, the uncertainty of RS time series data based AD would be 6% (defined by PNG FRL), while ALP based AD for forest area as well as harvested timber volume indicates higher uncertainty due to manual archiving data system.

8. Emission Reduction

Emissions reduction (ER) shows the improvement provided by the project against the baseline emissions. It is calculated as follows, where ER can be estimated from the Baseline emissions (*BLe*) set based on the last 10 reference years of logging emissions, and the Project emissions (*PRe*) with application of improved or reduced-impact logging practices for climate change mitigation (RIL-C), based on the compliance of PNG forestry regulations such as LCoP and PMCP, as mitigation measures to coventional logging.

$$ER = BLe - PRe$$

As adopted by ERPD (2019) of East Kalimantan, prior to mitigation project commencement, project emission can be estimated based on assumptions for improvement. It is assumed that the adoption of RIL-C practices is gradual due to possibilities that not all concessions want to integrate RIL support program at the beginning but gradually adopted at the later stage, which would result as emission reductions, as described in the below table (just an example). This is based on an assumption that increase of concessions adopted RIL/RIL-C practices and improved their logging operation continuously throughout the crediting period of 5 years.

Year	Baseline emissions	Improvement % by Project	Emission reduction
2025	1 MtCO2e	10%	0.1 MtCO2e
2026	1 MtCO2e	11%	0.11 MtCO2e
2027	1 MtCO2e	12%	0.12 MtCO2e
2028	1 MtCO2e	13%	0.13 MtCO2e
2029	1 MtCO2e	14%	0.14 MtCO2e
		Average improvement: 12%	ER = 0.60 MtCO2e

Table 7-1: Example of Emission Reduction Calculation

Once the project starts, project emissions will be monitored, reported, and verified (MRV) periodically. For MRV purpose, not only impact parameters (emission reduction, residual tree damages) but also performance parameters need to be defined clearly. Performance

Parameters measure how well RIL/RIL-C practices are implemented and adhered to in logging operations, in order to track the effectiveness of identified (pre-set) practices. In case of PNG, potential RIL practices through enhancing the compliance with LCoP/PMCP are identified based on robust consultations among stakeholders but yet to decide performance indicators. Once parameters are set and a project commences, project emissions as well as emission reduction should be carefully monitored and assessed accordingly.

9. Conclusion

The "Method for Field Carbon Monitoring of Logging Emissions at PNGFA-JICA Project Pilot Sites" is a critical advancement in PNG's efforts to monitor and manage forest carbon emissions. By combining internationally accepted methodologies with national regulatory frameworks, it provides a robust and scalable solution for assessing logging-related emissions.

Since commercial logging is the primary driver of forest degradation in PNG, a transparent and scientifically robust monitoring system is essential for effective policy implementation. This methodology ensures that emission estimates are accurate, enabling better decision-making for conservation efforts. Additionally, by distinguishing between conventional logging and RIL, it provides a pathway for improved logging practices to gain recognition in carbon financing schemes. This contributes to PNG's broader environmental sustainability goals while creating incentives for the forestry sector to adopt best management practices.

The methodology's focus on setup-scale monitoring allows for detailed impact assessments, which can be scaled up for broader application at the concession level. The integration of field-based measurements with remote sensing enhances the robustness of monitoring, allowing for cross-validation of logging impacts. This hybrid approach ensures cost-effective yet reliable emissions tracking.

One of the methodology's strengths is its alignment with PNG's reporting and regulatory requirements. By utilizing data from official logging records and national forest inventories, it ensures consistency with government reporting systems. This enhances its applicability and ease of adoption by forestry authorities while maintaining compliance with international carbon standards. The inclusion of QA/QC protocols further strengthens its credibility, ensuring that emissions data can withstand scrutiny in carbon market mechanisms.

In conclusion, this methodology provides a well-structured and scientifically grounded framework for monitoring logging-related carbon emissions in PNG. Its integration with international best practices, alignment with national policies, and potential for supporting carbon credit initiatives make it a valuable tool for sustainable forest management. By enhancing transparency and accountability in PNG's forestry sector, it contributes to balancing economic development with conservation goals, ensuring long-term environmental and economic benefits.

[END]

10. Annex

1) Glossary
2) Project Manual for Field Carbon Measurements
3) Project Manual for Logging Carbon Emission Calculation

Annex 1: Glossary

Term	Abbreviation	Definition
Activity Data	AD	The measure of human activity leading to emissions, e.g., logging area (ha) or harvested timber volume (m^3).
Above-Ground Biomass	AGB	The total biomass of living trees above the ground, including stems, branches, and leaves.
Below-Ground Biomass	BGB	The total biomass of tree roots below ground.
Biomass Expansion Factor	BEF	A factor used to estimate total tree biomass from merchantable wood volume.
Carbon Dioxide Equivalent	CO_2e	A standard unit for measuring greenhouse gas emissions based on their global warming potential.
Carbon Fraction	CF	The proportion of biomass that is carbon, typically assumed as 0.47 for dry matter.
Emission Factor	EF	The rate of carbon emissions per unit of logging activity, measured in tC/ha or tC/m^3.
Extracted Log Emission	ELE	Carbon emissions from logs removed from the forest during timber harvesting.
Logging Damage Emission	LDE	Carbon emissions resulting from residual biomass loss, including unextracted log portions, damaged trees, and residues.
Logging Infrastructure Emission	LIE	Carbon emissions from the clearing of forests for roads, skid tracks, and log landings.
Baseline Emissions	BLe	Estimated historical emissions from conventional logging over a reference period (e.g., 10 years).
Project Emissions	PRe	Actual emissions recorded under an improved or reduced-impact logging scenario.
Total Carbon Emissions	TCE	The sum of all emissions caused by logging activities, including extracted log, damage, and infrastructure emissions.

Emission Reduction	ER	The difference between baseline emissions and project emissions (ER = BLe - PRe).
Forest Reference Level	FRL	A benchmark for forest carbon emissions, used in national greenhouse gas reporting and REDD+ implementation.
National Forest Inventory	NFI	A national dataset providing information on forest biomass, species composition, and carbon stocks.
Reduced-Impact Logging	RIL	A set of logging practices designed to minimize environmental damage and carbon emissions.
Reduced-Impact Logging for Climate Mitigation	RIL-C	A specialized form of RIL that focuses on reducing carbon emissions and qualifying for carbon financing.