PROPOSED NEW BASELINE AND MONITORING METHODOLOGY FOR REDD

CONTENTS

Section I. Summary and applicability of the baseline and monitoring methodologies

1. Methodology title (for baseline and monitoring) and history of submission

Methodology title:

COMPONENT A: Baseline and monitoring methodology for conservation projects that avoid planned land use conversion in peat swamp forests, Version 5.1, December 2009

If this methodology is a based on a previous submission or an approved methodology, please state the relevant reference number (ARNMXXXX/AR-AMXXXX). Explain briefly the main differences and/or rationale for not using the approved methodology.

All coloured text in this document is taken directly from a listed approved CDM AR methodology, the certified Noel Kempff avoided deforestation project, or the current versions of the AD Partners REDD methodology modules. **Leaving the text in this color will assist others in identifying text that has already been approved or that is pending approval.**
Green: AR-AM0004
Teal: NMBL_NKCAP_A
Maroon: AR-AM0007
Orange: AR-AM0005
Purple: AD Partners REDD Methodology Module

No approved methodology is available at this time, because these activities are currently not eligible to the CDM. Although avoided land use conversion is eligible as a REDD activity under the VCS, peat is not currently an eligible carbon pool under the VCS. The CDM A/R methodology template as used here was the only methodology template available at the time that this methodology was first developed. As such, the methods outlined in this methodology are comprehensive and more or less consistent with the VCS modules that address planned deforestation.

The leakage approach outlined in this methodology was adapted from the most current version of the leakage module for “estimation of emissions from activity shifting for avoided planned deforestation” as summarized in the Avoided Deforestation Partners REDD Methodological Module (v. 1.0, April 2009). This module is currently under review and has not yet been approved by the VCS Board. To account for future updates to this module, the proposed leakage methodology prescribes the adaptation of the most current version.

2. Selected baseline approach for REDD project activities

Choose one (delete others):

☐ Existing or historical, as applicable, changes in carbon stocks in the carbon pools within the project boundary;
☐ Changes in carbon stocks in the carbon pools within the project boundary from a land use that represents an economically attractive course of action, taking into account barriers to investment;
☒ Changes in carbon stocks in the pools within the project boundary from the most likely land use at the time the project starts.

Explanation/justification of choice:

3. Applicability conditions

A proposed project activity must satisfy the following conditions in order for the proposed new methodology to be applicable:

A. The methodology was developed for (and is applicable to) preventing land use change on undrained tropical peat swamp forests in southeast Asia only; it is not applicable to peatlands in other regions or climatic zones (boreal peat bogs, etc.) or to previously drained peatlands. Forest shall be defined according to the host country's forest definition as agreed upon under UNFCCC participation that includes minimum thresholds for area, height and crown cover. Peat shall be defined as organic soils with at least 65% organic matter and a minimum thickness of 50 cm[1].
B. The application of the procedure for determining the baseline scenario in Section II.3 leads to the conclusion that baseline approach (c) is the most appropriate choice for determination of the baseline scenario.
C. The methodology is applicable only for avoiding complete conversion of peat swamp forests to another known land use; it is not applicable for avoiding forest degradation. It is assumed that land preparation during the conversion of peat forest would have removed all existing aboveground biomass stocks through logging and/or burning.
D. The methodology is applicable only for preventing planned land use conversion in known, discrete parcel(s) of peatland, not for deforestation trends that follow a "frontier" approach. The land use conversion avoided must be in areas officially and legally designated for and under direct threat of such conversion, and the area and specific geographic location of all planned land use conversions in the baseline must be known and come from written documentation including land use conversion permits, government records, concession maps, etc. Planned deforestation must be projected to occur within ten years of the project start date.
E. The methodology is applicable only for avoiding land use change that would be caused by corporate or governmental entities (plantation companies, national or provincial forestry departments, etc.) and not by community groups, community-based organizations, individuals or households.
F. Net peat drainage to establish the land use change in the baseline scenario would not exceed one meter in depth.
G. Carbon stocks in dead wood and litter can be expected to further decrease (or increase less) in the absence of the project activity during the time frame that coincides with the crediting period of the project activity.
H. The parcel(s) of peat swamp forest to be converted to another land use must not contain human settlements (towns, villages, etc.) or human activities that lead directly to deforestation, such as clearing for agriculture or grazing land. Activities that involve the utilization of natural resources within the project boundary that do not lead to deforestation are permitted (e.g., selective logging, collection of NTFPs, fuelwood collection, etc.) as this degradation is accounted for in the monitoring methodology.
I. The biomass of vegetation within the project boundary at the start of the project is at steady-state, or is increasing due to recovery from past disturbance, and so monitoring project GHG removals by vegetation can be conservatively neglected if desired.
J. The volume of trees extracted as timber per hectare prior to land conversion in the baseline is conservatively assumed to be equivalent to the total volume (or biomass) of all trees above the minimum size class sold in the local timber market.

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[1] Rieley, J.O. and S.E Page. 2005. Wise Use of Tropical Peatland: Focus on Southeast Asia. Alterra, Wageningen, The Netherlands. 237 p. ISBN 90327-0347-1.

K. The project boundary shall be hydrologically intact such that the project area is not affected by drainage activities that are occurring or outside the project area in a defined buffer zone (if applicable) at the start of the project (as detected from satellite or other remote sensing imagery). Both the project boundary and the buffer zone (if applicable) shall be monitored for new drainage activities over the life of the project. The width of the buffer zone to be monitored shall be set to a default value of 3 km from the edge of the project boundary or the distance to the edge of the peat dome, whichever is smaller. The monitoring methodology accounts for the impacts of future drainage activities that occur within the project boundary, but if future monitoring detects significant new drainage within the buffer zone (such as that associated with new canals designed for transportation by boat or for developing plantations), then this methodology is no longer applicable in its current form and it shall be revised to take into consideration the extent of the outside drainage activity's impact on GHG emissions occurring within the project boundary. This drainage impact shall be determined using a combination of hydrological modelling and field measurements and shall be done in collaboration with at least two peat experts. If new scientific findings suggest influences for which the prescribed buffer zone would not offer effective separation between the project boundary and external drainage activities, the methodology should be revised to reflect a revised buffer width.

L. If the agent of planned deforestation in the baseline is the Government or a yet to be determined agent that will receive Government sanction to deforest, the total land area allocated by the government for planned deforestation must be shown not to have increased solely for the purpose of eliciting REDD credits.

Proof that each applicability condition has been fulfilled shall be outlined in the PDD.

Methodology procedure:

The baseline methodology outlines transparent and conservative methods to estimate the avoided net greenhouse gas emissions resulting from project activities implemented to stop planned land use conversion on tropical peat forest.

This methodology allows for the estimation of changes in carbon stocks in selected aboveground carbon pools and also accounts for peat emissions. It conservatively draws the baseline scenario from amongst the plausible scenarios, and presents methods to transparently estimate the GHG emissions expected from the most likely land use(s) prior to the start of the project activity.

Explanation/justification (if methodology procedure is not self-explanatory):

4. Selected carbon pools

Table A: Selected carbon pools

Carbon pools	Selected (answer with Yes or No)	Justification / Explanation of choice
Above ground tree biomass	**Yes**	Major carbon pool subject to the project activity
Aboveground non-tree biomass	**Yes**	Major carbon pool subject to the project activity
Belowground biomass	No	It is assumed that belowground biomass is included in the peat component. Additionally, root to shoot ratios for peat swamp forests are highly uncertain; root biomass can be estimated using a

		model based on aboveground biomass estimates, but the model is intended for upland forests only and may not apply to peat swamp forests[2]
Dead wood	No	Conservative approach under applicability condition
Litter	No	Conservative approach under applicability condition[3].
Peat	**Yes**	Major carbon pool subject to the project activity
Soil organic carbon	No	The soil component is included in the peat component.
Wood Products	**Yes**	Removal of timber is associated with deforestation in the baseline, and significant quantities of carbon can be stored in long-term wood products rather than being emitted into the atmosphere. Thus the quantity of live biomass going into long-term timber products in the baseline scenario is included.

5. Summary description of major baseline and monitoring methodological steps

a. Baseline methodology:

The methodology adopts baseline approach 22(c) – "*changes in carbon stocks in the pools within the project boundary from the most likely land use at the time the project starts*", taking into account national, sectoral, and local policies influencing the land use prior to the start of the project activity; the scope of project alternatives relative to the baseline; and barriers to implement the avoided deforestation project activity.

This methodology anticipates several possible baseline scenarios and uses the "*Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM Project Activities*[4]"

Baseline methodology steps

1. The project boundary is defined for all eligible discrete parcels of land to be protected from land use change that are under the control of the project participants at the starting date of the project activity.
2. Stratification of the project area is based on local site classification maps/tables, the most updated land-use/land-cover maps, satellite images, vegetation maps, landform maps as well as supplementary surveys, and the baseline land-use/land-cover is determined separately for each stratum.
3. The baseline scenario is determined by applying the "*Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM Project Activities*."

[2] Cairns, M.A., S. Brown, E.H. Helmer, G.A. Baumgardner. 1997. Root biomass allocations in the world's upland forests. Oecologia 111:1-11.

[3] According to field measurements conducted by the project proponent in 57 plots using standard operating procedures as outlined in AR-AM0007, the litter pool represents approximately 0.01% of the total aboveground carbon stocks in peat swamp forests (0.009 ± 0.0017 t C ha^{-1}); therefore a decrease in this carbon pool does not result in a significant GHG emission. Sulistiyanto (2004) also showed that litter makes up 2.4% of the above and belowground tree biomass in both mixed swamp and low pole peat forests in Central Kalimantan. If the REDD project were an A/R project, the litter pool would be deemed an insignificant emission (<5% of total emissions) using the CDM approved tool titled "Tool for testing significance of GHG emissions in A/R CDM project activities".

[4] Available at http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html

4. The _ex ante_ calculation of baseline net GHG emissions is performed by strata. The baseline carbon stock change in aboveground biomass is estimated based on methods developed in IPCC 2003 Good Practice Guidance (GPG) for Land Use, Land-Use Change and Forestry (LULUCF) as well as on methods that utilize high resolution aerial digital imagery. The baseline GHG emissions from peat are estimated based on regional data on CO_2 emissions and emission factors.
5. Additionality is demonstrated using the latest version of the "*Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM Project Activities*" approved by the CDM Executive Board.
6. The _ex ante_ actual net GHG emissions avoided are estimated for each stratum in the project activity.
7. Leakage emissions, including carbon stock decrease**s** and peat emissions outside the project boundary, are accounted for activity displacement[5].

b. Monitoring methodology:

The monitoring methodology outlines methods to monitor both carbon stock changes in the living biomass and peat emissions of project activities and increases in the GHG emissions that result from the implementation of the project activity. It outlines methods and procedures that complement the provisions of the baseline methodology. As per this methodology, the baseline scenario is identified and quantified *ex ante* at the beginning of the project activity and shall be re-assessed/revised every 10 years in accordance with VCS guidelines to take into account the latest scientific and technical understanding. The methodology outlines methods for assessing and accounting for displacement of economic activities attributable to the project activity.

The methodology recommends the use of remotely sensed data to monitor the project carbon stocks as well as disturbances within the project boundary. The methodology specifies annual monitoring and supports the recording of disturbances, if any. It recommends the adoption of standard operating procedures for monitoring, data collection and archival in order to maintain the integrity of the data collected in the monitoring process.

Monitoring methodology steps

1. The project implementation is monitored, including the project boundary, the area prevented from land use change and any activities that reduce carbon stocks or result in peat emissions in the project area over the crediting period. If the project boundary is not a functionally discrete hydrological unit, a buffer zone around the project boundary is also monitored to ensure against drainage activities occurring outside the project boundary that could potentially impact peat emissions in the project area, per Applicability Condition K of this methodology.
2. Stratification of the project area is monitored periodically because two different strata may become similar enough in terms of carbon to justify their merging. The *ex-post* stratification considers monitoring of the project strata to verify the applicability of the *ex-ante* stratification, and variables that influence the strata. The *ex post* stratification procedures facilitate cost-effective, consistent and accurate monitoring of carbon stock changes of the project during the crediting period.
3. Baseline net GHG emissions are not monitored in this methodology. The methodology prescribes validity of the baseline identified *ex ante* at the start of the project activity for the crediting period, thereby avoiding the need for monitoring of the baseline over the crediting period, and achieves savings in the costs associated with baseline monitoring.

[5] Accounting for leakage due to fossil fuel use for transport is no longer required, see EB 42 and 44

4. The calculation of *ex-post* actual net GHG emissions avoided is based on data obtained from sample plots, regional literature values and methods developed in IPCC GPG-LULUCF to estimate carbon stock changes in the carbon pools and peat emissions.
5. Leakage due to activity displacement is monitored and accounted in order to calculate the net GHG emissions avoided.
6. The QA/QC guidelines proposed as part of the monitoring plan verify the accuracy and consistency of field measurements and ensure the integrity of data collection, management of project databases and the database archival during the crediting period.
7. When a project is undergoing validation and verification, non-permanence risk analysis shall be conducted by both the project developer and the verifier at the time of verification in accordance with the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination.

Section II. Baseline methodology description

1. Project boundary

Methodology procedure:

(Taken directly from AR-AM0005)

a) Project participants shall define the "project boundary" at the beginning of a proposed project activity and shall provide the geographical coordinates of lands to be included, so as to allow clear identification for the purpose of verification. The remotely sensed data with adequate spatial resolution, officially certified topographic maps, land administration and tenure records, and/or other official documentation that facilitates the clear delineation of the project boundary can be used. The data shall be geo-referenced, and preferably provided in digital format. In the absence of requisite data and documentation, field surveys shall be undertaken to delineate the project boundary.

The project boundary includes emissions sources and gases as listed in Table B.

b) The original project boundary is fixed over the project life. Even if unforeseen circumstances arise within the project boundary such as deforestation, degradation, fire, or other land use change, the project boundary cannot be shifted. The project boundary as well as areas of change must be monitored as part of the project's monitoring activities and GHG emissions associated with these changes must be calculated. Any emissions that occur within the project boundary in a given year after the start of the project must be subtracted from the carbon benefits estimated for that year.

Table B: Gaseous emissions from sources other than those resulting from changes in carbon pools[6]

Sources	Gas	Included/ excluded	Justification / Explanation of choice
Burning of aboveground biomass	CO_2	**No**	However, carbon stock decreases due to burning are accounted as a carbon stock change
	CH_4	**Yes**	Non-CO_2 gas emitted from biomass burning
	N_2O	**Yes**	Non-CO_2 gas emitted from biomass burning
Peat oxidation from drainage	CO_2	**Yes**	Main gas of this source
	CH_4	No	Drainage has been shown to have a small effect on CH_4 emission budgets[7]; the highest proportional CH_4 flux forms only <0.2% of the CO_2 emissions in drained peat soils.[8,9]

[6] Fertilizer and fossil fuel use by vehicles have been omitted from Table B as per recommendations of EB 42 and 44.

	N_2O	No	Potential emission is negligibly small[10, 11]
Burning of peat	CO_2	**Yes**	Emissions are accounted using an emission factor
	CH_4	**Yes**	Non-CO_2 gas emitted from peat burning; emissions are accounted using an emission factor
	N_2O	No	N_2O is not typically a measured trace gas emission from peat burning[12]; potential emission differential between natural and burned peat is negligible[13]

c) The project boundary can be established in such a way that it constitutes a functionally discrete hydrological unit, as determined in consultation with experts in peat hydrology. If the project boundary represents such a discrete unit, a buffer zone around the project boundary does not need to be established and monitored to account for the influence of outside drainage activities. Where a project boundary does not represent a discrete hydrological boundary, the project developer shall establish and monitor a buffer zone around the project boundary appropriate for the expected risks, determined by the potential area of influence from external drainage activities. The width of this buffer area around the project boundary shall be determined as the edge of the peat dome or 3 km from the project boundary, whichever is smaller. If a buffer zone less than 3 km around the project boundary is to be applied, this value shall be defended in the PDD and methods for monitoring impacts of drainage activities in the reduced buffer zone shall be designed in consultations with experts in peat hydrology.

Explanation/justification of choice (only if space in the table is not sufficient).
Explain/justify differences in emission sources covered by baseline and project activity, if any:

2. Stratification

Methodology procedure:

(Taken directly from AR-AM0004)

In this methodology, stratification is achieved in four steps:

Step 1 stratifies the project area according to pre-existing natural conditions and baseline projections into *m* BL strata;

Step 2 stratifies the project area according to projected project activities into *m* PS strata; and

Step 3 achieves the final *ex ante* stratification by combining the results of step 2 with ongoing treatment and stratum boundary monitoring.

Step 4 stratifies the area of leakage due to activity displacement into *m* LK strata

Step 1: Stratification according to pre-existing conditions and baseline projections:

a) Define the factors influencing carbon stock changes in carbon pools.
b) Collect local site classification maps/tables, the most updated land use/cover maps, land planning maps, aerial imagery, satellite images, soil maps, vegetation maps, landform maps, peat depth maps, and literature reviews of site information concerning key factors identified above.
c) Do a preliminary stratification based on the collected information.
d) Carry out supplementary sampling for site specifications for each stratum, including as appropriate:
    - Existing aboveground carbon stocks or vegetation types
    - Present and past land tenure and land use;

[7] Couwenberg, J., R. Dommain and H. Joosten. 2009. Greenhouse gas fluxes from tropical peatlands in Southeast Asia. Global Change Biology, in press.

[8] Jauhiainen, J., S. Limin, H. Silvennoinen, H. Vasander. 2008. Carbon dioxide and methane fluxes in drained tropical peat before and after hydrological restoration. Ecology 89(12): 3503-3514.

[9] CH_4 fluxes were calculated as insignificant following the CDM "Tool for testing significance of GHG emissions in A/R CDM project activities"

- Baseline land use in the absence of project activity:
- Peat depth differences: Stratification of the project area by peat depth is important when depth in parts or all of the project area is **less than** the depth that is projected to be lost in the baseline scenario over time. For example, peat subsidence resulting from drainage can occur in the baseline scenario only until the available supply of peat has been oxidized, after which baseline emissions from drainage would be zero. Current literature on peat subsidence suggests that drained tropical peat in SE Asia subsides at an initial rate of 4.5 cm yr^{-1}, translating into a loss of approximately 1.35 m over a 30-year project life[22,23]. If peat depth across the project area is greater than the depth of peat lost via subsidence and burning in the baseline scenario over the project life, then it is assumed that there is an adequate supply of carbon in peat in the project area to sustain the assumed baseline scenario and stratification by peat depth is unnecessary. Evidence for exceeding this peat depth threshold within the project boundary shall be presented in the PDD. If peat depth in parts or all of the project area is shallower than the depth that would be lost to drainage and burning in the baseline scenario over the project life, a peat depth map shall be created from sample points across the project area. The sampling design and methods for developing the peat depth map shall be outlined in the PDD.

e) Do the final stratification of the baseline scenario based on supplementary information collected from d) above. Distinct strata should differ significantly in terms of their baseline net greenhouse gas emissions.
f) For highly variable landscapes the option exists to carry out a systematic unbiased sampling to determine the percentage of the project area occupied by each stratum. At each plot, based on the site specifications found, the plot shall be assigned to one of the strata identified in paragraph f. Sampling intensity in this step shall be the greater of 100 plots, or 1 plot per 5 hectares of project area. The proportions defined will be applied across the project area to define baseline condition. Subsequent sampling for determination of baseline carbon shall take place in each of the defined strata.

Step 2: Stratification according to the project activity:
a) Define the project activities
b) Distinct strata should differ significantly from each other in terms of their actual net greenhouse gas avoided emissions.

Step 3: Final *ex ante* stratification:
a) Verifiably delineate the boundary of each stratum as defined in step 2 using GPS, analysis of geo-referenced spatial data, or other appropriate techniques. Check the consistency with the overall project boundary. Coordinates may be obtained from GPS field surveys or analysis of geo-referenced spatial data, including remotely sensed images, using a Geographical Information System (GIS).
b) Preferably, project participants shall build geo-referenced spatial databases in a GIS platform for each parameter used for stratification of the project area under the baseline and the project scenario. This will facilitate consistency with the project boundary, precise overlay of baseline and project scenario strata, transparent monitoring and *ex post* stratification.

Step 4: Leakage stratification: similar to Step 1 above, except areas analyzed are those to which activities are expected to be displaced (*ex ante*) or have been displaced (*ex post*) rather than the project boundary.
a) Define the factors influencing carbon stock changes in carbon pools.
b) Collect local site classification maps/tables, the most updated land use/cover maps, land planning maps, aerial imagery, satellite images, soil maps, vegetation maps, landform maps, peat depth maps, and literature reviews of site information concerning key factors identified above.

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[22] Wosten, J.H.M., A.B. Ismail, A.L.M. van Wijk. 1997. Peat subsidence and its practical implications: a case study in Malaysia. Geoderma 78: 25-36.

[23] The Wosten et al. (1997) study did not state the depth to which the peat was drained, only that the peat was drained in the 1960s and that total peat depth in the region varies between 1 and 10 m.

c) Stratify based on the information collected in (b) above.

Note: In the equations used in this methodology, the letter *i* is used to represent a stratum and the letter *m* for the total number of strata.

m_{BL} is the number of *ex ante* defined baseline strata as determined with step 1. m_{BL} remains fixed for the entire crediting period.

m_{PS} is the number of strata in the project scenario as determined *ex ante* with step 2.

m_{LK} is the number of strata in the leakage scenario as determined with step 4.

The methodology can include one or more categories of proposed land use conversions, land cover types and/or peat depths, all designated as different strata (*i*) in the baseline scenario. If more than one land use conversion is anticipated in the baseline scenario (e.g., part of the land within the baseline scenario is expected to undergo one type of conversion whereas other parts of the land are expected to convert to another type), the project participants shall stratify the lands under the baseline according to the likely land use/land cover or combinations of land use/land cover types in the baseline, as per Section II.2 above. Where baseline activities are expected to affect peat reserves to a depth that exceeds the available peat supply in some areas of the project boundary, project participants shall also consider peat depth in their stratification scheme.

The sampling framework, including sample size, plot size, plot shape and plot location should be specified in the PDD. When estimating existing carbon stocks within baseline strata for an avoided emissions project, permanent sampling plots are not necessary because these carbon stocks do not need to be tracked over time. Therefore, temporary sampling plots can be used. However, if project proponents choose to monitor increases in carbon stocks in the vegetation over the life of the project, permanent sampling plots must be installed. The number of sample plots is estimated based on accuracy and costs.

The number, size and location of sampling plots shall be determined using the most current version of the CDM Tool "*Calculation of the number of sample plots for measurements within A/R CDM project activities.*"[24]

If baseline carbon stocks are to be estimated remotely using high resolution aerial imagery, plots should be established on the imagery using the same methods as for establishing plots on the ground. The number, size and location of sample plots to be established and measured can be calculated as for ground plots above using imagery-derived information such as the area of each stratum (A_i), the total project area (A), sample plot size (AP), standard deviation for each stratum (st_i), desired precision (DLP) and average value of the estimated quantity (Q).

Explanation/justification (if methodology procedure is not self-explanatory):

3. Procedure for selection of the most plausible baseline scenario

Methodology procedure:

[24] http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-03-v2.pdf

The most current version of the CDM "*Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM Project Activities*", approved by the CDM Executive Board, should be used to determine the most plausible baseline scenario. As of October 2009, the most current version of the tool can be accessed on the UNFCCC website at http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html.

Explanation/justification (if methodology procedure is not self-explanatory):

4. Additionality

Methodology procedure:

The most current version of the CDM "*Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM Project Activities*", approved by the CDM Executive Board, should be used to determine additionality through investment, barrier and common practice analyses, as applicable. As of October 2009, the most current version of the tool can be accessed on the UNFCCC website at http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html.

Explanation/justification (if methodology procedure is not self-explanatory):

5. Estimation of baseline GHG emissions

Methodology procedure:

This methodology outlines methods to estimate the GHG emissions from peat and the changes in carbon stocks in aboveground biomass of peat swamp forests that would occur in the absence of project activities.

Baseline net GHG emissions are represented as follows:

$$C_{BSL} = \sum_{t=1}^{t^*} \sum_{i=1}^{m_{BL}} C_{B,it} \quad \textbf{(1)}$$

and:

$$C_{B,it} = \Delta C_{B,AG,it} + E_{B,p,it} \quad \textbf{(2)}$$

where:

C_{BSL} = sum of peat emissions and carbon stock changes in aboveground biomass under the baseline scenario; t CO_2-e

$C_{B,it}$ = sum of peat emissions and carbon stock changes in aboveground biomass under the baseline scenario for stratum *i* at time *t*; t CO_2-e.

$\Delta C_{B,AG,it}$ = sum of carbon stock changes in aboveground biomass under the baseline scenario for stratum *i* at time *t*; t CO_2-e.

$E_{B,p,it}$ = Peat GHG emissions under the baseline scenario for stratum *i*, time *t*; t CO_2-e
i = 1, 2, 3, …m_{BL} baseline strata
t = 1, 2, 3, …t^* years elapsed since the start of the project activity

Note: In this methodology Eq. 1 is used to estimate baseline net greenhouse gas emissions for the period of time elapsed between project start (t=1) and the year t=t^*, t^* being the year for which baseline net greenhouse gas emissions are estimated.

A value for the average peat emissions and carbon stock changes in aboveground biomass under the baseline scenario for stratum *i* is needed in Sections II.7.2 and Section III.7.2 to calculate leakage. This average value is calculated as:

$$\overline{C}_{B,it} = \frac{C_{B,it}}{A_{B,it}^{cleared}} \qquad \textbf{(3)}$$

Where:

$\overline{C}_{B,it}$ = average peat emissions and carbon stock changes in aboveground biomass under the baseline scenario for stratum *i* at time *t*; t CO_2e ha^{-1}
$C_{B,it}$ = sum of peat emissions and carbon stock changes in aboveground biomass under the baseline scenario for stratum *i* at time *t*; t CO_2-e.
$A_{B,it}^{cleared}$ = Area cleared under the baseline scenario for stratum *i*, in time *t*; ha

5.1 Estimation of $\Delta C_{B,AG,it}$ (carbon stock changes in aboveground biomass)

For all strata, carbon stock changes in aboveground biomass can be estimated as the sum of carbon stock changes resulting from initial land clearing and from future land-use activities:

$$\Delta C_{B,AG,it} = E_{timber,it} + E_{B,BiomassBurn,it} - R_{B,growth,it} + E_{harvest,it} \qquad \textbf{(4)}$$

where:

$\Delta C_{B,AG,it}$ = sum of carbon stock changes in aboveground biomass under the baseline scenario in stratum *i* at time *t*; t CO_2-e
$E_{timber,it}$ = sum of carbon stock changes in aboveground biomass due to timber extraction prior to land clearing in stratum *i* at time *t*; t CO_2-e
$E_{B,BiomassBurn,it}$ = sum of carbon stock changes in aboveground biomass due to biomass burning for stratum *i* at time *t* under the baseline scenario; t CO_2-e
$R_{B,growth,it}$ = sum of carbon stock changes in aboveground biomass due to biomass growth of living vegetation on the future land-use for stratum *i* at time *t*; t CO_2-e
$E_{harvest,it}$ = sum of carbon stock changes in aboveground biomass due to harvest activities at rotation on baseline future land-use for stratum *i* at time *t*; t CO_2-e

5.1.1 Estimation of $E_{timber,it}$ (GHG emissions from timber extraction before land clearing)

Per applicability condition J of this methodology, in the baseline scenario the project land is assumed to be logged for timber prior to land clearing. Emissions from timber extraction are calculated as:

$$E_{timber,it} = (C_{B,it}^{extracted} - C_{B,it}^{woodproducts}) \cdot \frac{44}{12} \quad \textbf{(5)}$$

$C_{B,it}^{extracted}$ can be estimated by calculating the biomass of the logs that would be extracted in the baseline case using either allometric equations or a biomass expansion factor to convert from volume to biomass. When estimating the biomass of timber removed (based on a minimum diameter threshold), it is conservative to assume that the biomass of the entire aboveground component (leaves, branches, etc.) of each harvested tree is removed with the logs extracted, leaving no slash behind to burn.

$$C_{B,it}^{extracted} = B_{B,it}^{\log ged} \cdot CF \cdot A_{B,it}^{\log ged} \quad \textbf{(6)}$$

$$C_{B,it}^{woodproducts} = C_{B,it}^{extracted} \cdot p \quad \textbf{(7)}$$

where:

$C_{B,it}^{extracted}$	= carbon stocks from trees extracted under the baseline scenario in stratum *i* at time *t*; t C
$C_{B,it}^{woodproducts}$	= carbon stocks moving into long-term wood products under the baseline scenario for stratum *i* at time *t*; t C
$B_{B,it}^{\log ged}$	= timber biomass logged under the baseline scenario for stratum *i* at time *t*; t ha^{-1}
CF	= carbon fraction of dry matter (0.5 t C / t biomass); dimensionless
$A_{B,it}^{\log ged}$	= Area of land logged under the baseline scenario for stratum *i*, in time *t*; ha
p	= percent of harvest industrial roundwood going into long term wood products

As per Applicability Condition D in Section I.3, the area and specific geographic location of all planned land use conversions in the baseline must be known and come from written documentation including land use conversion permits, government records, concession maps, etc. The annual area of forest conversion to the proposed land use type $A_{B,it}^{cleared}$ (and $A_{B,it}^{\log ged}$ if applicable) must be estimated from plantation permit records or records of previous land use conversion also meeting the applicability conditions of this methodology. If annual rates of conversion to the proposed land use type are unknown (i.e., common practice is unknown), the maximum area to be accounted for as converted peatlands per year should be conservatively capped at the regional rate of land use change.

If it is unknown whether the land would be logged prior to conversion, then logging should be assumed because some of the carbon extracted as timber will be stored as long-term wood products; this is a conservative scenario.

The biomass of timber extracted under the baseline scenario $B_{B,it}^{\log ged}$ must be estimated in Equation 6. As per Applicability Condition J outlined in section I.3, it is assumed that the size class and species of trees sold in the local timber market would have been extracted in the project area prior to clearing. Species and minimum diameter classes sold in the local timber market can be obtained from government records, timber records of existing logging operations, surveys of illegal logging activities, sawmill surveys, or records of previous land use conversion also meeting the applicability conditions of this methodology.

Alternatively, market surveys can be conducted to determine which species and size classes are sold. It is conservative to assume that all species of a small diameter class threshold would be sold for timber, leaving fewer remaining trees to burn when the land is cleared.

Using plot data collected in Sec. II **5.1.2.1 Estimation of** $MC_{B,AG\_tree,it}$ and locally-derived volume or biomass equations, estimate the biomass per unit area (t dry matter ha^{-1}) that would be expected to be logged in each stratum *i* at time *t* by following the steps below. If local equations are not available, more generic equations based on forest type can be used, with demonstration of the applicability of the equation outlined in the PDD (e.g., through limited destructive harvest measurements collected in the project area).

Step 1: For each plot measured to calculate $MC_{B,AG\_tree,it}$, calculate the biomass of each tree that would have been extracted, defined as all trees within each plot that exceed the minimum diameter threshold. Add the biomass of all trees together and multiply by a plot expansion factor which is proportional to the area of the measurement plot. This is divided by 1,000 to convert from kg to t.

BEF Method:

$$PV_{B,it} = \frac{\left(\sum_{tr=1}^{TR} TV_{B,AG\_tree,tr} \cdot XF \right)}{1000} \quad \textbf{(8)}$$

$$PB_{B,it} = PV_{B,it} \cdot \phi_i \cdot BEF \cdot CF \quad \textbf{(9)}$$

Allometric or Aerial Imagery Method:

$$PB_{B,it} = \frac{\left(\sum_{tr=1}^{TR} TB_{B,tr} \cdot XF \right)}{1000} \quad \textbf{(10)}$$

$$XF = \frac{10{,}000}{AP} \quad \textbf{(11)}$$

where:

$PB_{B,it}$	=	Plot level biomass to be extracted under the baseline scenario in stratum *i* at time *t*; t ha^{-1}
$TV_{B,tr}$	=	Volume per tree *tr* in trees to be extracted under the baseline scenario; m^3 tree^{-1}
$TB_{B,tr}$	=	Biomass per tree *tr* in trees to be extracted under the baseline scenario; t d.m. tree^{-1}
XF	=	Plot expansion factor from per plot values to per hectare values
ϕ_i	=	volume-weighted average wood density; t d.m. m^{-3} merchantable volume

BEF = biomass expansion factor for conversion of biomass of merchantable volume to above-ground biomass; dimensionless.

AP = Plot area; m^2

tr = 1, 2, 3, …, *TR* trees (*TR* = total number of trees in the plot expected to be extracted)

Step 2: Calculate the average biomass expected to be extracted within each stratum by averaging across plots within a stratum:

$$B_{B,it}^{\log ged} = \frac{\sum_{pl=1}^{PL_{it}} PB_{B,it}}{PL_{it}} \quad \textbf{(12)}$$

where:

$B_{B,it}^{\log ged}$ = timber biomass logged under the baseline scenario for stratum *i* at time *t*; t ha^{-1}

$PB_{B,it}$ = Plot level biomass to be extracted under the baseline scenario in stratum *i*, time *t*; t d.m. ha^{-1}

pl = Plot number in stratum *i*; dimensionless

PL_{it} = Total number of plots in stratum *i*, time *t*; dimensionless

5.1.2 Estimation of $E_{B,BiomassBurn,it}$ (GHG emissions from biomass burning for land clearing)

As per Applicability Condition C in section I.3, it is assumed in the baseline scenario that all remaining biomass that is not harvested as timber would be cleared by fire to prepare the site for a new land use activity.
(taken directly from AR-AM0004)

Therefore, it is assumed that tree vegetation is partially or totally harvested before burning and that:

- The carbon stock decrease in the harvested tree biomass is estimated using the methods outlined in Section 5.1.1 above;
- The aboveground biomass of the harvested trees is subtracted from the total aboveground biomass estimate used for the calculation of non-CO_2 emissions from burning;

Based on revised IPCC 1996 Guidelines for LULUCF, this type of emissions can be estimated (whenever double counting of carbon stock losses is avoided) as follows:

$$E_{B,BiomassBurn,it} = E_{B,BiomassBurn,CO2,it} + E_{B,BiomassBurn,N2O,it} + E_{B,BiomassBurn,CH4,it} \quad \textbf{(13)}$$

where:

$E_{B,BiomassBurn,it}$ = total increase in CO_2-e emissions under the baseline scenario as a result of aboveground biomass burning for land clearing in stratum *i* at time *t*; t CO_2-e

$E_{B,BiomassBurn,CO2,it}$ = CO_2 emission from biomass burning under the baseline scenario in stratum *i* at time *t*; t CO_2-e

$E_{B,BiomassBurn,N2O,it}$ = N_2O emission from biomass burning under the baseline scenario in stratum i at time t; t CO_2-e

$E_{B,BiomassBurn,CH4,it}$ = CH_4 emission from biomass burning under the baseline scenario in stratum i at time t; t CO_2-e

and:

$$E_{B,BiomassBurn,CO2,it} = \left(C_{B,AC,it} \cdot PBB_{B,it} \cdot CE\right)\frac{44}{12} \qquad \textbf{(14)}$$

where:

$E_{BiomassBurn,CO2,it}$ = CO_2 emission from biomass burning under the baseline scenario in stratum i at time t-; t CO_2-e

$C_{B,AC,,it}$ = estimated above-ground biomass carbon stock before burning in the baseline scenario for stratum i, time t; t C

$PBB_{B,it}$ = average proportion of $C_{B,AC,it}$ burnt under the baseline scenario in stratum i, time t; dimensionless

CE = average biomass combustion efficiency (IPCC default=0.5); dimensionless

Because the land is being cleared for another land use in the baseline scenario, all of the biomass that is not extracted as timber is assumed to be burned and therefore for this methodology the proportion burned in the baseline ($PBB_{B,it}$) is assumed to be equal to 1.

The combustion efficiencies CE may be chosen from Table 3.A.14 of IPCC GPG-LULUCF. If no appropriate combustion efficiency can be used, the IPCC default of 0.5 should be used. The nitrogen-carbon ratio (N/C ratio) is approximated to be about 0.01. This is a general default value that applies to leaf litter, but lower values would be appropriate for fuels with greater woody content, if data are available. Emission factors for use with above equations are provided in Tables 3.A.15 and 3.A.16 of IPCC GPG-LULUCF.

The aboveground carbon stock before burning ($C_{B,AC,it}$) is assumed to be equal to the difference between the carbon stock in the tree and non-tree pools prior to logging and the carbon extracted as timber during logging operations:

$$C_{B,AC,it} = \left[MC_{B,AG,it} * A_{B,it}^{cleared}\right] - C_{B,it}^{extracted} \qquad \textbf{(15)}$$

where:

$C_{B,AC,it}$ = estimated above-ground carbon stock before burning under the baseline scenario for stratum i, time t; t C

$MC_{B,AG,it}$ = mean carbon stock in above-ground living biomass under the baseline scenario for stratum i, time t; t C ha^{-1}

$A_{B,it}^{cleared}$ = Area cleared under the baseline scenario for stratum i, in time t; ha

$C_{B,it}^{extracted}$ = carbon stocks from trees extracted under the baseline scenario in stratum i at time t; t C

Emissions of non-CO_2 gases are given by:[25]

$$E_{B,BiomassBurn,N2O,it} = E_{B,BiomassBurn,CO2,it} \cdot \frac{12}{44} \cdot (N/Cratio) \cdot ER_{N_2O} \cdot \frac{44}{28} \cdot GWP_{N_2O} \quad \textbf{(16)}$$

$$E_{B,BiomassBurn,CH4,it} = E_{B,BiomassBurn,CO2,it} \cdot \frac{12}{44} \cdot ER_{CH_4} \cdot \frac{16}{12} \cdot GWP_{CH_4} \quad \textbf{(17)}$$

where:

$E_{B,BiomassBurn,CO2,it}$ = CO_2 emission from aboveground biomass burning under the baseline scenario in stratum *i*, time *t*; t CO_2-e.

$E_{B,BiomassBurn,N2O,it}$ = N_2O emission from aboveground biomass burning under the baseline scenario in stratum *i*, time *t*; t CO_2-e

$E_{B,BiomassBurn,CH4,it}$ = CH_4 emission from aboveground biomass burning under the baseline scenario in stratum *i*, time *t*; t CO_2-e

$N/Cratio$ = nitrogen-carbon ratio (IPCC default = 0.01); dimensionless

ER_{N2O} = emission ratio for N_2O (IPCC default value = 0.007); t CO_2-e $(t\ C)^{-1}$

ER_{CH4} = emission ratio for CH_4 (IPCC default value = 0.012); t CO_2-e $(t\ C)^{-1}$

GWP_{N2O} = Global Warming Potential for N_2O (= 310 for the first commitment period); t CO_2-e $(t\ N_2O)^{-1}$

GWP_{CH4} = Global Warming Potential for CH_4 (= 21 for the first commitment period); t CO_2-e $(t\ CH_{4)})^{-1}$

5.1.2.1 Mean carbon stocks in aboveground biomass ($MC_{B,AG,it}$)

Mean carbon stocks in aboveground biomass are expressed as the sum of biomass in the tree and non-tree components:

$$MC_{B,AG,it} = MC_{B,AG\_tree,it} + MC_{B,AG\_nontree,it} \quad \textbf{(18)}$$

where:

$MC_{B,AG,it}$ = Mean carbon stock in above-ground biomass under the baseline scenario in stratum *i*, time *t*; t C ha^{-1}.

$MC_{B,AG\_tree,it}$ = Mean aboveground biomass carbon stock in tree biomass in stratum *i* at time *t*; t C ha^{-1}

$MC_{B,AG\_nontree,it}$ = Mean aboveground biomass carbon stock in non-tree biomass in stratum *i* at time *t*; t C ha^{-1}

<u>Estimation of mean carbon stocks in aboveground non-tree biomass</u> ($MC_{B,AG\_nontree,it}$)

[25] Refers to Table 5.7 in 1996 Revised IPCC Guideline for LULUCF and Equation 3.2.19 in IPCC GPG-LULUCF

The non-tree woody aboveground biomass pool includes trees smaller than the minimum tree size measured in the tree biomass pool, all shrubs, and all other non-herbaceous live vegetation[26]. Non-tree vegetation can be sampled using destructive sampling frames and/or, where suitable, in sampling plots in combination with an appropriate allometric equation for shrubs.

The mean carbon stock in aboveground non-tree biomass is calculated for each stratum by adding together results calculated using the sampling frame method and the allometric equation method:

$$MC_{B,AG\_nontree,it} = MC_{AG\_nontree\_sample,it} + MC_{AG\_nontree\_allometric,it} \qquad \textbf{(19)}$$

where:

$MC_{B,AG\_nontree,it}$ = Mean aboveground non-tree biomass carbon stock in stratum *i* at time *t*; t C ha^{-1}

$MC_{B,AG\_nontree\_sample,it}$ = Mean aboveground non-tree biomass carbon stock in stratum *i* at time *t* calculated from sampling frame method; t C ha^{-1}

$MC_{B,AG\_nontree\_allometric,it}$ = Mean aboveground non-tree biomass carbon stock in stratum *i* at time *t* calculated from allometric equation method; t C ha^{-1}

Sampling Frame Method:

In strata where non-tree vegetation is spatially variable, large frames should be used (e.g., 1-2 m radius circle). Where non-tree vegetation is homogeneous, smaller frames can be used (e.g., 30 cm radius). Generally, the frame is placed at four random locations per randomly selected GPS point (or per plot, where mean carbon stocks in trees are also measured). At each location, all vegetation originating from inside the frame is cut at the base and weighed. The wet weight of the four sample frames is added together. These four sampling frames create one non-tree sample plot. One representative subsample from all four sub-sample frames is weighed and taken from field. The collected subsample is oven dried and weighed to determine the dry weight. The wet to dry ratio of the subsample is then used to estimate the dry weight of the original sample.

The mean carbon stock per unit area in the above ground non-tree biomass (sampling method) is calculated for each stratum as:

$$MC_{AG\_nontree\_sample,it} = \frac{1}{A_{SFP,i}} * \sum_{sf=1}^{SFP_i} MC_{AG\_nontree\_sample,sf,it} * CF_{non-tree} \qquad \textbf{(20)}$$

$$A_{SFP,i} = \sum_{sfp=1}^{SFP_i} \sum_{SF=1}^{4} A_{sampleframe} \qquad \textbf{(21)}$$

where:

[26] Pursuant to AR-WG 21 that the GHG emissions from removal of herbaceous vegetation are insignificant in A/R CDM project activities, these emissions can be neglected in A/R baseline and monitoring methodologies.

$MC_{AG\_nontree\_sample,it}$	= Mean aboveground non-tree biomass carbon stock in stratum *i* at time *t* calculated using sampling frame method; t C ha^{-1}
$MC_{AG,nontree\_sample,sf,,it}$	Carbon stock in above ground non-tree vegetation in sample plot *sf* in stratum *i* at time *t* from sampling frame method; kg d.m.
$CF_{non\text{-}tree}$	Carbon fraction of dominant non-tree vegetation species; dimensionless
$A_{SFP,i}$	Total area of all non-tree sampling plots in stratum i; m^{-2}
$A_{sampleframe}$	Area of one sampling frame; m^{2}
sfp	*1, 2, 3 … SFP_i* sample plots in stratum *i*
i	*1, 2, 3 … M* strata
t	*1, 2, 3 … t* years elapsed since the start of the project activity
sf	*1,2,3 up to 4* sampling frames per sample plot

Allometric Equation Method:

The allometric equation method for estimating aboveground non-tree biomass carbon stocks may be used for shrubs, bamboo, or other vegetation types where individuals can be delineated clearly.

Step 1: Select or develop an appropriate allometric equation (species-specific if possible, otherwise for a similar species).

Step 2: Estimate carbon stock in above-ground biomass for each individual *l* in the sample plot *r* located in stratum *i* using the selected or developed allometric equation:

$$MC_{AG\_nontree\_allometric,i,r,t} = \sum_{l=1}^{N_{r,i,t}} f_q(vegetation\_parameters) * CF_q \quad \textbf{(22)}$$

where:

$MC_{AG\_nontree\_allometric,i,r,t}$	Carbon stock in above-ground biomass of non-tree sample plot *r* in stratum *i* at time *t* from allometric equation method; t C
CF_q	Carbon fraction of biomass for species *q*; t C t^{-1} d.m.
f_q*(vegetation parameters)*	Allometric equation for species *q* linking parameters such as stem count, diameter of crown, height, or others to above-ground biomass of an individual; t. d.m. individual^{-1}
i	*1, 2, 3, …m* strata
r	*1,2,3, …R* non-tree allometric method sample plots in stratum *i*
q	*1, 2, 3 … Q* non-tree species
l	*1, 2, 3, … $N_{l,i,sp,t}$* sequence number of individual trees in sample plot *r* in stratum *i* at time *t*
t	*0,1,2,3 …t* years elapsed since start of the project activity

Step 3: Calculate the mean carbon stock in aboveground biomass for each stratum, converted to carbon dioxide equivalents:

$$MC_{AG\_nontree\_allometric,it} = \frac{1}{Ar_i} * \sum_{r=1}^{R_i} MC_{AG\_nontree\_allometric,i,r,t} \quad \textbf{(23)}$$

where:

$MC_{AG\_nontree\_allometric,it}$	Mean aboveground biomass carbon stock in stratum *i* at time *t* from allometric equation method; t C ha^{-1}
$MC_{AG\_nontree\_allometric,i,r,t}$	Aboveground biomass carbon stock in nontree vegetation in sample plot *r* of stratum *i* at time *t* from non-tree allometric sample plots, t C
Ar_i	Total area of all non-tree allometric method sample plots in stratum *i*; ha
r	*1,2,3, …R* non-tree allometric method sample plots in stratum *i*
i	*1, 2, 3 … M* strata
t	*0,1,2,3, …t* years elapsed since the start of the project activity

Estimation of mean carbon stocks in aboveground tree biomass **(** $MC_{B,AG\_tree,it}$ **)**

Three methods are available to measure aboveground tree biomass carbon in each stratum *i*: (1) the Aerial Imagery method; (2) the Biomass Expansion Factor (BEF) method; and (3) the Allometric Equations method. Refer to Sec II.2 above for information regarding the number of plots required when setting up field and/or virtual plots.

Aerial Imagery Method

The aerial imagery method is preferable when carbon stocks must be estimated over large and/or inaccessible areas of forest. Methods in this section are based on Brown et al. (2005)[27] and Slaymaker (2003)[28].

AIM Step 1: On the ground, measure diameter at breast height (DBH), total tree height and crown area of individual trees of varying diameters and species found within the project region. Sample size should be large enough to capture the variability in DBH and crown areas of trees in the project boundary. Estimate biomass of each tree using the allometric equations method that relates DBH or DBH and height to biomass (see Allometric Equations method below).

Crown area is estimated as the average area of two ellipses, where each ellipse is estimated based on canopy measurements in perpendicular compass directions:

$$A_{crown} = \frac{A_{ellipse1} + A_{ellipse2}}{2} \qquad \textbf{(24)}$$

and:

$$A_{ellipse1} = \pi \times \frac{(\cos(angle_N) * dist_N) + (\cos(angle_S) * dist_S) + \frac{dbh}{100}}{2} \times \frac{(\cos(angle_E) * dist_E) + (\cos(angle_W) * dist_W) + \frac{dbh}{100}}{2} \qquad \textbf{(25)}$$

$$A_{ellipse2} = \pi \times \frac{(\cos(angle_{NE}) * dist_{NE}) + (\cos(angle_{SW}) * dist_{SW}) + \frac{dbh}{100}}{2} \times \frac{(\cos(angle_{NW}) * dist_{NW}) + (\cos(angle_{SE}) * dist_{SE}) + \frac{dbh}{100}}{2} \qquad \textbf{(26)}$$

where:

A_{crown} = area of tree crown, m^2

$A_{ellipse1}$ = area of tree crown calculated using north, south, east and west-facing measurements;

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[27] Brown, S., T. Pearson, D. Slaymaker, S. Ambagis, N. Moore, D. Novelo, and W. Sabido. 2005. Creating a virtual tropical forest from three-dimensional aerial imagery: Application for estimating carbon stocks. Ecological Applications 15: 1083-1095.

[28] Slaymaker, D. 2003. Using georeferenced large-scale aerial videography as a surrogate for ground validation data. In: Wulder, M.A. and S.E. Franklin (eds.), 2003. Remote Sensing of Forest Environments: Concepts and Case Studies. Kluwer, ISBN 1-4020-7405-0, pps. 469-488. http://www.wkap.nl/prod/b/1-4020-7405-0.

m^2

$A_{ellipse2}$ = area of tree crown calculated using northeast, southeast, northwest and southwest-facing measurements; m^2
$angle_N$ = angle formed between observer's eye and end of farthest observable canopy branch facing north; degrees
$angle_S$ = angle formed between observer's eyeand end of farthest observable canopy branch facing south; degrees
$angle_E$ = angle formed between observer's eye and end of farthest observable canopy branch facing east; degrees
$angle_W$ = angle formed between observer's eye and end of farthest observable canopy branch facing west; degrees
$angle_{NE}$ = angle formed between observer's eye and end of farthest observable canopy branch facing northeast; degrees
$angle_{SE}$ = angle formed between observer's eye and end of farthest observable canopy branch facing southeast; degrees
$angle_{NW}$ = angle formed between observer's eye and end of farthest observable canopy branch facing northwest; degrees
$angle_{SW}$ = angle formed between observer's eye and end of farthest observable canopy branch facing southwest; degrees
$dist_N$ = distance from observer to end of first canopy branch facing north; meters
$dist_S$ = distance from observer to end of first canopy branch facing south; meters
$dist_E$ = distance from observer to end of first canopy branch facing east; meters
$dist_W$ = distance from observer to end of first canopy branch facing west; meters
$dist_{NE}$ = distance from observer to end of first canopy branch facing northeast; meters
$dist_{SE}$ = distance from observer to end of first canopy branch facing southeast; meters
$dist_{NW}$ = distance from observer to end of first canopy branch facing northwest; meters
$dist_{SW}$ = distance from observer to end of first canopy branch facing southwest; meters
dbh = diameter at breast height of tree; cm

To take measurements, observer stands against the trunk of the tree and moves around the trunk to each compass direction.

Tree height is estimated based on field measurements of angle and distance to top of tree from two vantage points:

$$H_{tree} = \frac{[dist_1 * \tan(angle_1)] + H_{eye} + [dist_2 * \tan(angle_2)] + H_{eye}}{2} \qquad \textbf{(27)}$$

where:

H_{tree} = total height of tree, m
$dist_1$ = horizontal distance from observer to trunk of tree from first vantage point; m
$dist_2$ = horizontal distance from observer to trunk of tree from second vantage point; m
$angle_1$ = angle from ground to top of tree measured from first vantage point; degrees
$angle_2$ = angle from ground to top of tree measured from second vantage point; degrees
H_{eye} = height from ground to observer's eye; m

AIM Step 2: Create a relationship between a combination of the height and/or crown area and the biomass of each tree observed. Options include:

$$TB_{B,AG\_tree,tr} = f(H_{tree}) \tag{28}$$

$$TB_{B,AG\_tree,tr} = f(A_{crown}) \tag{29}$$

$$TB_{B,AG\_tree,tr} = f(A_{crown} \cdot H_{tree}) \tag{30}$$

where:

$TB_{B,AG\_tree,tr}$ = above-ground biomass of a tree *tr* under the baseline scenario; kg tree^{-1}
H_{tree} = height of tree, m
A_{crown} = area of tree crown, m^2

$f(H_{tree})$ = an allometric equation linking above-ground tree biomass (kg tree^{-1}) to tree height
$f(A_{crown})$ = an allometric equation linking above-ground tree biomass (kg tree^{-1}) to crown area
$f(A_{crown} \cdot H_{tree})$ = an allometric equation linking above-ground tree biomass (kg tree^{-1}) to crown area multiplied by tree height

Using collected data, all equation types should be tested. It has been found that a regression equation based on crown area as the only independent variable works well for trees, otherwise a regression based on both crown area and height should be used if adding height improves the equation. A minimum coefficient of determination (R^2) of 0.70 should be attained, and an independent sample of 5-15 trees should be destructively harvested and used to verify the equation. At least 75% of actual biomass values shall fall within the 95% prediction intervals of the predicted biomass values, with no systematic bias.

AIM Step 3: In a standard aircraft, collect high resolution (10-15 cm per pixel) imagery in systematically spaced, overlapping parallel transects evenly distributed over the project boundary where land cover change is expected to occur. Imagery collection components should include a high definition video camera, a real-time differential correction geographic positioning system, a laptop computer, drives capable of storing large amounts of data, and software that enables imagery and GPS information to be associated with each other.

AIM Step 4: Use software such as the ERDAS-IMAGINE Leica Photogrametry Suite to create overlapping high resolution images in each transect and uses the file's accuracy information, level and scale of overlapping images to create a 3-dimensional stereo view. The resulting digital stereo model can be viewed clearly on a computer monitor when the user wears glasses that enable 3-dimensional (3D) viewing.

AIM Step 5: Randomly select high resolution images to analyze and establish a virtual plot on each image selected. The selection of images should follow the same sampling scheme as in the selection of ground plots. Where stratification is needed, the images should be divided into the same strata as ground measurements and random images should be selected from each stratum. As with ground measurements, select a preliminary set of virtual plots for analysis for each stratum and convert to carbon in vegetation by following the steps below. Using the preliminary estimates of the variation, the actual number of virtual plots needed per stratum to sample with a targeted precision value can be calculated using methods outlined in Sec. II 5.2.1. Plots can then be equally spaced along transects in a systematic manner (e.g., select one stereo-pair of images out of every 10 images collected). The center point of each image selected should be designated as the plot center.

AIM Step 6: For each of the selected plots, create a feature project within Stereo Analyst that contains empty feature classes for plant types (typically broadleaf trees and palm trees for closed canopy tropical forest), and import a shapefile of the virtual plot. Stereo Analyst automatically performs 3D calculations such as the 3D coordinates (X, Y and Z coordinates) of a point, area and perimeter of a polygon. Create polygons around the crowns of each vegetation type. After digitization, the crown area (m^2) for each tree is calculated automatically by the software.

Tree height (m) of each digitized tree on the image is calculated as the difference between the Z coordinate at the top of the tree and the Z coordinate at a point on the ground close to the tree trunk. The software populates the Z coordinate of the top of the tree automatically for each digitized crown polygon, and the interpreter indicates the Z coordinate for a point on the ground. Since the images typically represent closed canopy forest, designating the Z coordinate for a point on the ground close to the base of the tree is not always possible. In cases where the ground is not visible, the Z coordinate of the average of three closest possible ground sites is recorded.

AIM Step 7: Estimate the biomass of each tree in the virtual plot by relating crown areas and/or heights to biomass using Equations 27, 28 or 29 chosen in AIM Step 2. Estimate carbon stock in above-ground biomass using the following equation: (taken directly from AR-AM0004)

$$TC_{B,AG\_tree,tr} = TB_{B,AG\_tree,tr} \cdot CF \qquad \textbf{(31)}$$

where:

$TC_{B,AG\_tree,tr}$ = Carbon stock in above-ground biomass of a tree *tr* under the baseline scenario; kg tree^{-1}

$TB_{B,AG\_tree,,tr}$ = Above-ground biomass of a tree *tr* under the baseline scenario; kg tree^{-1}

CF = Carbon fraction, t C (tonne d.m.)$^{-1}$, IPCC default value = 0.5

AIM Step 8 : Calculate the above-ground biomass carbon per plot on a per area basis by summing the biomass carbon per tree within each virtual plot and multiplying by a plot expansion factor which is proportional to the area of the measurement plot. This is divided by 1,000 to convert from kg to t.

$$PC_{B,AG\_tree,it} = \frac{\left(\sum_{tr=1}^{TR} TC_{B,AG\_tree,tr} \cdot XF\right)}{1000} \qquad \textbf{(32)}$$

$$XF = \frac{10{,}000}{AP} \qquad \textbf{(33)}$$

where:

$PC_{B,AG\_tree,jt}$= Plot level carbon stock in above ground biomass under the baseline scenario in stratum *i*, time *t*; t C ha^{-1}

$TC_{B,AG\_tree,tr}$ = Carbon stock in above-ground biomass per tree *tr* under the baseline scenario; kg C $tree^{-1}$

XF = Plot expansion factor from per plot values to per hectare values

AP = Plot area; m^2

tr = 1, 2, 3, …, TR trees (TR = total number of trees in the plot)

AIM Step 9: Calculate mean carbon stock within each stratum by averaging across plots in a stratum or stand:

$$MC_{B,AG\_tree,it} = \frac{\sum_{pl=1}^{PL_{it}} PC_{B,AG\_tree,it}}{PL_{it}} \quad \textbf{(34)}$$

where:

$MC_{B,AG\_tree,it}$ = Mean carbon stock in above-ground biomass under the baseline scenario in stratum *i*, time *t*; t C ha^{-1}.

$PC_{B,AG,it}$ = Plot level mean carbon stock in above-ground biomass under the baseline scenario in stratum *i*, time *t*; t C ha^{-1}.

pl = Plot number in stratum *i*; dimensionless

PL_{it} = Total number of plots in stratum *i*, time *t*; dimensionless

(taken directly from AR-AM0004)

BEF Method

***BEF Step 1*:** Measure the diameter at breast height (DBH, at 1.3 m above-ground) and preferably height of all the trees in the sample plots above a minimum DBH. The minimum DBH varies depending on tree species and climate, for instance, the minimum DBH may be as small as 2.5 cm in arid environments where trees grow slowly, whereas it could be up to 10 cm for humid environments where trees grow rapidly (IPCC GPG-LULUCF).

***BEF Step 2*:** Estimate the volume of the commercial component of trees based on locally derived equations, then sum for all trees within a plot and express as volume per unit area (e.g., m^3/ha). It is also possible to combine step 1 and step 2 if there are field instruments (e.g. relascope) that measure volume of each tree directly.

***BEF Step 3*:** Choose BEF: The BEF varies with local environmental conditions, species and age of trees, the volume of the commercial component of trees. These parameters can be determined by either developing a local regression equation or selecting from national inventory, Annex 3A.1 Table 3A.1.10 of IPCC GPG LULUCF, or from published sources. If a significant amount of effort is required to develop local BEFs, involving, for instance, harvest of trees, then it is recommended not to use this method but rather to use the resources to develop local allometric equations as described in the allometric method below (refers to Chapter 4.3 in IPCC GPG LULUCF). If that is not possible either, national species specific defaults are for BEF can be used. Since BEF is age dependent, it is desirable to use age-dependent equations. Stem-wood volume can be very small in young stands and BEF can be very large, while for old stands BEF is usually significantly smaller. Therefore using average BEF value may result in significant errors for both young stands and old stands. It is preferable to use allometric equations, if the equations are available, and as a second best solution, to use age-dependent BEFs (but for very young trees, multiplying a small number for stemwood with a large number for the BEF can result in significant error). Below ground root biomass is an excluded pool and so is not estimated. It is assumed root biomass is captured in peat estimates.

***BEF Step 4*:** Converting the volume of the commercial component of trees into carbon stock in above-ground biomass and below-ground biomass via basic wood density, BEF and carbon fraction, given by[29]:

$$MC_{B,AG\_tree,it} = MV_{B,AG\_tree,it} \cdot \phi_i \cdot BEF \cdot CF \qquad \textbf{(35)}$$

where:

$MC_{B,,AG\_tree,it}$ = mean carbon stock in above-ground biomass per unit area under the baseline scenario for stratum *i,* time *t;* t C ha^{-1}

$MV_{B,AG\_tree,it}$ = Mean merchantable volume under the baseline scenario in stratum *i* at time *t*; m^3 ha^{-1}

ϕ_i = specific wood density of harvested wood, for stratum *i*,; t d.m. m^{-3}

BEF = biomass expansion factor for conversion of biomass of merchantable volume to above-ground biomass; dimensionless.

CF = carbon fraction; t C (tonne d.m.)$^{-1}$; IPCC default value = 0.5.

<u>Allometric Method</u>

***Allo Step 1*:** Measure the diameter at breast height (DBH, at 1.3 m above ground) and possibly, depending on the form of the equation, height of all the trees in sample plots above a minimum DBH. The minimum DBH varies depending on tree species and climate, for instance, the minimum DBH may be as small as 2.5 cm in arid environments where trees grow slowly, whereas it could be up to 10 cm for humid environments where trees grow rapidly (IPCC GPG-LULUCF).

***Allo Step 2*:** Choose or establish appropriate allometric equations.

$$TB_{B,AG\_tree,tr} = f(DBH, H_{tree}) \qquad \textbf{(36)}$$

where:

$TB_{B,AG\_tree,tr}$ = above-ground biomass of a tree *tr* under the baseline scenario; kg tree^{-1}

$f(DBH,H_{tree})$ = an allometric equation linking above-ground tree biomass (kg tree^{-1}) to diameter at breast height (DBH) and possibly tree height (H_{tree}) measured in plots for stratum *i*, time *t*,.

The allometric equations are preferably local-derived and species-specific. When allometric equations developed from a biome-wide database, such as those in Annex 4A.2, Tables 4.A.1 and 4.A.2 of IPCC GPG LULUCF, are used, it is necessary to verify by destructively harvesting, within the project area but outside the sample plots, a few trees of different sizes and estimate their biomass and then compare against a selected equation. If the biomass estimated from the harvested trees is within about ±10% of that predicted by the equation, then it can be assumed that the selected equation is suitable for the project. If this is not the case, it is recommended to develop local allometric equations for the project use. For this, a sample of trees, representing different size classes, is destructively harvested, and its total biomass is determined. The number of trees to be destructively harvested and measured depends on the range of size classes and number of species—the greater the heterogeneity the more trees are required. If resources

[29] IPCC GPG-LULUCF Equation 4.3.1

permit, the carbon content can be determined in the laboratory. Finally, allometric equations are constructed relating the biomass with values from easily measured variables, such as the DBH and total height (see Chapter 4.3 in IPCC GPG LULUCF). Also generic allometric equations can be used, as long as it can be proven that they are wrong on the conservative side, i.e., they underestimate carbon sequestration.

***Allo Step 3*:** Estimate carbon stock in above-ground biomass per tree using selected allometric equations applied to the tree measurements in Step 1

$$TC_{B,AG\_tree,tr} = TB_{B,AG\_tree,tr} \cdot CF \quad \textbf{(37)}$$

where:

$TC_{B,AG\_tree,tr}$ = Carbon stock in above-ground biomass per tree under the baseline scenario; kg C tree^{-1}

$TB_{B,AG\_tree,tr}$ = Above-ground biomass of a tree tr under the baseline scenario; kg tree^{-1}

CF = Carbon fraction, t C (tonne d.m.)-1, IPCC default value = 0.5.

Allo Step 4: Calculate the above-ground biomass carbon per plot on a per area basis. Calculate by summing the biomass carbon per tree within each plot and multiplying by a plot expansion factor which is proportional to the area of the measurement plot. This is divided by 1,000 to convert from kg to t.

$$PC_{B,AG\_tree,it} = \frac{\left(\sum_{tr=1}^{TR} TC_{B,AG\_tree,tr} \cdot XF \right)}{1000} \quad \textbf{(38)}$$

$$XF = \frac{10{,}000}{AP} \quad \textbf{(39)}$$

where:

$PC_{B,AG\_tree,it}$ = Plot level carbon stock in above ground biomass under the baseline scenario in stratum *i*, time *t*; t C ha^{-1}

$TC_{B,AG\_tree,tr}$ = Carbon stock in above-ground biomass per tree under the baseline scenario; kg C tree^{-1}

XF = Plot expansion factor from per plot values to per hectare values

AP = Plot area; m^2

tr = Tree (TR = total number of trees in the plot)

Allo Step 5: Calculate mean carbon stock within each stratum. Calculate by averaging across plots in a stratum or stand:

$$MC_{B,AG\_tree,it} = \frac{\sum_{pl=1}^{PL_{ik}} PC_{B,AG\_tree,it}}{PL_{it}} \quad \textbf{(40)}$$

where:

$MC_{AG,it}$ = Mean carbon stock in above-ground biomass under the baseline scenario in stratum i, time t; t C ha^{-1}.

$PC_{AG,it}$ = Plot level mean carbon stock in above-ground biomass under the baseline scenario in stratum i, time t; t C ha^{-1}.

pl = Plot number in stratum i, time t; dimensionless

PL_{it} = Total number of plots in stratum i, time t; dimensionless

5.2.3 Estimation of $R_{B,growth,it}$ (increase in carbon stocks due to aboveground biomass growth of vegetation in baseline land-use)

In the baseline scenario, a plantation is established after merchantable trees are harvested and the remaining biomass is cleared with fire. To remain conservative, the baseline calculations must account for the removal of CO_2 that occurs due to biomass growth of living trees on the future plantation. This biomass growth is estimated as:

$$R_{B,growth,it} = R_{ARB,it} \cdot A_{it}^{planted} \cdot \frac{44}{12} \quad \textbf{(41)}$$

where:

$R_{B,growth,it}$ = total annual increase in carbon stock due to growth of living trees on the future land-use in the baseline scenario for stratum i at time t; t CO_2-e

$R_{ARB,it}$ = average annual increase in carbon stock due to growth of living trees on the future land use in the baseline scenario for stratum i at time t; t C ha^{-1} yr^{-1}

$A_{it}^{planted}$ = area of biomass growth on future land use in the baseline scenario in stratum i at time t; ha

$\frac{44}{12}$ = ratio of molecular weights of CO_2 and carbon; dimensionless

$R_{ARB,it}$ is estimated based on field measurements or literature values. The area planted in stratum i at time t shall be estimated based on common practice as derived from field surveys at local plantation companies or set equal to the area cleared per year. If the baseline land use class is represented within the project boundary, mean carbon stocks will be measured as part of the stratification procedure in Step II.2 above. However, carbon stocks must be estimated for a range of vegetation ages to estimate the annual increase in carbon stocks on the baseline future land use. For example, carbon stocks must be measured on young, intermediate and old plantation sites at a minimum. To fulfil this requirement, carbon stocks can be measured at proxy sites outside the project boundary provided that site conditions are similar to those within the project area. To be conservative, all pools included in the estimation of current mean carbon stocks in aboveground biomass must also be included in the estimation of baseline future carbon stocks. When measuring carbon stocks at proxy sites, refer to Sec. II 5.1.2.1 for measurement of trees. Refer to Section II.2 for information regarding the number of plots required when setting up field and virtual plots.

If the future land use is not present within the project boundary and if proxy sites are not available to measure carbon stocks, then conservative estimates of biomass and/or carbon stock for different age classes shall be obtained from relevant literature.

Using the collected data, estimate the average increase in carbon stock due to vegetation growth on the future land use ($R_{ARB,it}$) by establishing an appropriate equation that links average aboveground carbon stock ($MC_{FLU,AC,it}$) to stand age using whichever function (linear or non-linear) fits the available data:

<u>Linear function:</u> This is the simplest method to estimate annual increase in carbon stock over time; the average annual increase in carbon stock is estimated as the slope of the regression line when the intercept is forced through the origin:

$$MC_{FLU,AC,it} = slp \cdot age + b \tag{42}$$

and:

$$R_{ARB,it} = slp \tag{43}$$

where:

$MC_{FLU,AC,it}$	= mean carbon stock in above-ground biomass on the future land use under the baseline scenario in stratum *i*, time *t*; t C ha^{-1}.
age	= age of stand; years
slp	= slope of regression line of biomass accumulation function; t C ha^{-1} yr^{-1}
b	= intercept of regression line (=zero, when forced through the origin); t C ha^{-1}
$R_{ARB,it}$	= average annual increase in carbon stock due to biomass growth of living trees on the future land use under the baseline scenario for stratum *i* at time *t*; t C ha^{-1} yr^{-1}

<u>Non-linear function</u>: A logistic (e.g., Chapman-Richards) function is often a better fit to detailed carbon stock measurements because biomass carbon typically accumulates quickly during early phases of stand establishment and levels off in later phases. If this is the case according to field data or literature values, the average annual increase in carbon stock due to biomass growth of living trees on the future land use can be estimated as:

$$R_{ARB,it} = MC_{FLU,AC,it} - MC_{FLU,AC,it-1} \tag{44}$$

and:

$$MC_{FLU,AC,it} = MaxYld * (1 - \exp(-prm1 \cdot age))^{prm2} \tag{45}$$

$$prm1 = -\frac{\ln[1-(0.8)^{\frac{1}{prm2}}]}{age_{peak}} \tag{46}$$

$$prm2 = \frac{1}{1-prm3} \tag{47}$$

where:

$MC_{FLU,AC,it}$	= mean carbon stock in above-ground biomass on the future land use under the baseline scenario, stratum *i*, time *t*; t C ha^{-1}.
$MC_{FLU,AC,it-1}$	= mean carbon stock in above-ground biomass on the future land use under the baseline scenario, stratum *i*, time *t*-1; t C ha^{-1}
$R_{ARB,it}$	= average annual increase in carbon stock due to biomass growth of living trees on the future land use under the baseline scenario for stratum *i* at time *t*; t C ha^{-1} yr^{-1}
age	= age of stand; years
MaxYld	= Maximum peak carbon yield; t C ha^{-1}
prm1	= intermediate calculation using fitted parameter *Prm2* when estimating biomass accumulation using non-linear function; dimensionless
prm2	= fitted parameter where *prm3* varies between 0 and 1 when fitting biomass accumulation values to a non-linear function; dimensionless
age_{peak}	= age of stand at peak production; years

5.2.4 Estimation of $E_{harvest,it}$ (GHG emissions from harvesting aboveground biomass on baseline future land use)

If short-rotation crops are envisaged to be planted as part of the new land use activity, then there would have been harvests taking place in the baseline scenario. Therefore, emissions that result from harvesting operations at the end of each rotation period should be accounted for. It is assumed that any biomass in the tree pool that is not harvested as timber at the end of the rotation period is burned to clear the land for the next rotation cycle.

Emissions from harvesting operations are estimated as:

$$E_{harvest,it} = \left(\frac{44}{12} \cdot \left(C_{BH,it}^{extracted} - C_{BH,it}^{woodproducts}\right)\right) + E_{BH,BiomasBurn,it} \quad \textbf{(48)}$$

where:

$E_{harvest,it}$	= emissions from harvesting operations in stratum *i* at time *t*; t CO_2-e
$C_{BH,it}^{extracted}$	= Carbon stocks of timber extracted at harvest *H* under the baseline scenario in stratum *i* at time *t*; t C
$C_{BH,it}^{woodproducts}$	= carbon stocks from harvest *H* moving into long term wood products under the baseline scenario for stratum *i* at time *t*; t C
$E_{BH,BiomassBum,it}$	= total increase in CO_2-e emissions as a result of aboveground biomass burning at harvest *H* under the baseline scenario in stratum *i* at time *t*; t CO_2-e.
$\frac{44}{12}$	= ratio of molecular weights of CO_2 and carbon; dimensionless

And:

$$C_{BH,it}^{extracted} = MC_{FLU,AC,it} \cdot PBH \cdot A_{BH,it}^{cleared} \quad \textbf{(49)}$$

$$C_{BH,it}^{woodproducts} = C_{BH,it}^{extracted} \cdot p \tag{50}$$

Where:

$C_{BH,it}^{extracted}$	= Carbon stocks from trees extracted at harvest *H* under the baseline scenario in stratum *i* at time *t*; t C
$C_{BH,it}^{woodproducts}$	= carbon stocks from harvest *H* moving into long term wood products under the baseline scenario for stratum *i* at time *t*; t C
$MC_{FLU,AC,it}$	= mean carbon stock in above-ground biomass on the future land use under the baseline scenario in stratum *i*, time *t*; t C ha^{-1}
PBH	= average proportion of aboveground carbon stock removed during harvest *H* under the baseline scenario for stratum *i*, time t; dimensionless
$A_{Bh,it}^{cleared}$	= Area cleared at harvest *H* under the baseline scenario for stratum *i*, in time *t*; ha
p	= percent of harvest industrial roundwood going into long term wood products; dimensionless

Emissions from aboveground biomass burning during harvesting operations ($E_{BH,BiomassBurn,it}$) are estimated based on revised IPCC 1996 Guidelines for LULUCF :
(taken directly from AR-AM0004)

$$E_{BH,BiomassBurn,it} = E_{BH,BiomassBurn,CO2,it} + E_{BH,BiomassBurn,N2O,it} + E_{BH,BiomassBurn,CH4,it} \tag{51}$$

where:

$E_{BH,BiomassBurn,it}$	= total increase in CO_2-e emissions as a result of aboveground biomass burning at harvest *H* under the baseline scenario in stratum *i* at time *t*; t CO_2-e.
$E_{BH,BiomassBurn,CO2,it}$	= CO_2 emission from biomass burning at harvest *H* under the baseline scenario in stratum *i* at time *t*; t CO_2-e.
$E_{BH,BiomassBurn,N2O,it}$	= N2O emission from biomass burning at harvest *H* under the baseline scenario in stratum *i* at time *t*; t CO_2-e.
$E_{BH,BiomassBurn,CH4,it}$	= CH_4 emission from biomass burning at harvest *H* under the baseline scenario in stratum *i* at time *t*; t CO_2-e.

and:

$$E_{BH,BiomassBurn,CO2,it} = \left(MC_{FLU,AC,it} \cdot (1 - PBH) \cdot A_{BH,it}^{cleared} \cdot PBB_{BH,it} \cdot CE\right) \cdot \frac{44}{12} \tag{52}$$

where:

$E_{BH,BiomassBurn,CO2,it}$	= CO_2 emission from biomass burning at harvest *H* under the baseline scenario in stratum *i* at time *t*; t CO_2-e
$MC_{FLU,AC,,it}$	= mean carbon stock in above-ground biomass on the future land use under the

baseline scenario in stratum *i*, time *t*; t C ha^{-1}

PBH = average proportion of aboveground carbon stock removed during harvest H under the baseline scenario for stratum *i*, time t;

$A^{cleared}_{Bh,it}$ = Area cleared at harvest H under the baseline scenario for stratum *i*, in time *t*; ha

$PBB_{BH,it}$ = average proportion of remaining aboveground carbon stocks burnt at harvest H under the baseline scenario in stratum *i*, time *t*; dimensionless

CE = average biomass combustion efficiency (IPCC default=0.5); dimensionless

$\frac{44}{12}$ = ratio of molecular weights of CO_2 and carbon; dimensionless

All of the tree biomass that is not extracted at harvest is assumed to be burned and therefore for this methodology the proportion of remaining aboveground carbon stocks burned at harvest H in the baseline ($PBB_{BH,it}$) is assumed to be equal to 1.

The combustion efficiencies CE may be chosen from Table 3.A.14 of IPCC GPG-LULUCF. If no appropriate combustion efficiency can be used, the IPCC default of 0.5 should be used. The nitrogen-carbon ratio (N/C ratio) is approximated to be about 0.01. This is a general default value that applies to leaf litter, but lower values would be appropriate for fuels with greater woody content, if data are available. Emission factors for use with above equations are provided in Tables 3.A.15 and 3.A.16 of IPCC GPG-LULUCF.

Emissions of non-CO_2 gases are given by:[30]

$$E_{BH,BiomassBurn,N2O,it} = E_{BH,BiomassBurn,CO2,it} \cdot \frac{12}{44} \cdot (N/Cratio) \cdot ER_{N_2O} \cdot \frac{44}{28} \cdot GWP_{N_2O} \quad \textbf{(53)}$$

$$E_{BH,BiomassBurn,CH4,it} = E_{BH,BiomassBurn,CO2,it} \cdot \frac{12}{44} \cdot ER_{CH_4} \cdot \frac{16}{12} \cdot GWP_{CH_4} \quad \textbf{(54)}$$

where:

$E_{BH,BiomassBurn,CO2,it}$ = CO_2 emission from aboveground biomass burning at harvest H under the baseline scenario in stratum *i*, time *t*; t CO_2-e.

$E_{BH,BiomassBurn,N2O,it}$ = N_2O emission from aboveground biomass burning at harvest H under the baseline scenario in stratum *i*, time *t*; t CO_2-e

$E_{BH,BiomassBurn,CH4,it}$ = CH_4 emission from aboveground biomass burning at harvest H under the baseline scenario in stratum *i*, time *t*; t CO_2-e

$N/Cratio$ = nitrogen-carbon ratio (IPCC default = 0.01); dimensionless

ER_{N2O} = emission ratio for N_2O (IPCC default value = 0.007); t CO_2-e./t C

[30] Refers to Table 5.7 in 1996 Revised IPCC Guideline for LULUCF and Equation 3.2.19 in IPCC GPG-LULUCF

ER_{CH4}	= emission ratio for CH_4 (IPCC default value = 0.012); t CO_2-e./t C
GWP_{N2O}	= Global Warming Potential for N_2O (= 310 for the first commitment period); t CO_2-e./t N_2O
GWP_{CH4}	= Global Warming Potential for CH_4 (= 21 for the first commitment period); t CO_2-e./t CH_4

5.3 Estimation of $E_{B,p,it}$ (GHG emissions from peat)

In addition to aboveground changes in carbon stocks, baseline emissions in stratum *i* at time *t* as calculated in Eq. 2 above also include increases in GHG emissions from peat. Baseline GHG emissions from peat impacted by land use conversion can be estimated as:

$$E_{B,p,it} = E_{B,Drainage,it} + E_{B,PeatBurn,it} \qquad \textbf{(55)}$$

where:

$E_{B,p,it}$	= total baseline GHG emissions from peat under the baseline scenario in stratum *i* at time *t*; t CO_2-e
$E_{B,Drainage,it}$	= GHG emissions from peat drainage under the baseline scenario in stratum *i* at time *t*; t CO_2-e
$E_{B,PeatBurn,it}$	= GHG emissions from peat burning under the baseline scenario in stratum *i*, time *t*; t CO_2-e

5.3.1 Estimation of $E_{B,Drainage,it}$ (GHG emissions from peat drainage)

GHG emissions from peat drainage resulting from land clearing activities for a baseline land-use activity are estimated as:

$$E_{B,drainage,it} = A_{B,drain,it} \cdot ME_{B,dd,it} \qquad \textbf{(56)}$$

and:

$$ME_{B,dd,it} = f(D_{B,drain,it}) \qquad \textbf{(57)}$$

where:

$E_{B,drainage,it}$	= CO_2 emissions from peat drainage under the baseline scenario in stratum *i* at time *t*, t CO_2-e
$A_{B,drain,it}$	= area of drainage impact under the baseline scenario in stratum *i*, time *t*; ha
$ME_{B,dd,it}$	= mean CO_2 emissions from drained peat in stratum *i*, time *t*; t CO_2 ha^{-1} yr^{-1}
$D_{B,,drain,it}$	= average depth of peat drainage or average depth to water table under the baseline scenario in stratum *i*, time *t*; cm

5.3.1.1 Depth of peat drainage ($D_{B,,drain,it}$)

Surveys should be conducted in proxy areas of land use change in the vicinity of the project area to determine common drainage practices including common drainage depth used for water management.

Results from the survey should be reported in the PDD and used in calculations. However, these data may not be available to project developers due to potential unwillingness of land managers of proxy areas to share specific practices and/or data.

Hooijer et al. (2006)[31] reports estimates of minimum and maximum values of drainage depths for the establishment of both large-scale plantations and mixed cropland/small-scale agriculture (Table 1). These estimates are considered conservative: e.g., average drainage depths well over 1 meter (up to 3 meters in some cases) are reported for many oil palm and pulpwood (Acacia) plantations. Therefore, in areas where peat depth exceeds 1.5 meters, projects with no data should apply a conservative drainage depth of 0.8 m (80 cm) when the baseline scenario is conversion to large-scale plantations and 0.4 m when the baseline scenario is conversion to small-scale agriculture. In cases where total peat depth is between 0.5 and 1.0 meters, drainage depth shall be conservatively assumed to be maintained at 50% of the total peat depth for conversion to large-scale plantations and 25% when the baseline scenario is to small-scale agriculture.

Table 1. Minimum, likely and maximum drainage depths within land use classes. Values are in meters. Reported in Hooijer et al. (2006).

Land Use	Minimum	Likely	Maximum
Large croplands, including plantations	0.80	0.95	1.10
Small-scale agriculture	0.40	0.60	0.80

After peat drainage occurs, land may be cleared with fire to prepare the site for the new land use, in which case the upper layer of peat will burn along with aboveground biomass. As a unit of peat can lose its carbon stock only once (from either oxidation due to drainage or combustion due to fire), potential double counting of emissions from drainage and burning must be avoided. If fire is assumed in the baseline as a method for clearing vegetation, the depth of peat burned (estimated in 5.3.2.1 below) shall be subtracted from the initial depth of peat drained when estimating drainage emissions. For example, if peat is drained to 80 cm and the top 34 cm is burned to clear vegetation, then drainage emissions shall be calculated based on a drainage depth of 46 cm.

5.3.1.2 Time dimension of peat drainage

Equation 57 that relates CO_2 emissions to drainage depth is assumed to be applicable throughout the life of the project. However, emissions from peat can occur only as long as there is a peat supply available to undergo oxidation. Over time, the peat surface subsides and the aerobic peat layer becomes thinner. Published information on peat subsidence rates from south-east Asian peatlands is scarce, but subsidence values of up to several dozen centimetres per year have been reported[32]. The observed subsidence of tropical peat soils shows linear dependency on water level; the limited number of observations from deeper drained tropical peatlands (i.e., >50 cm) suggest that subsidence levels off and remains at ~4.5 cm yr^{-1} at drainage depths below 50 cm.

Drainage of peat in the baseline case is assumed to occur from the year of initial drainage to *t^*, where *t^* is equal to the number of years after drainage that peat continues to be present assuming a subsidence rate of 4.5 cm yr^{-1}, calculated as:

[31] Hooijer, A., M. Silvius, H. Wosten and S. Page, 2006. PEAT-CO2, Assessment of CO_2 emissions from drained peatlands in SE Asia. Delft Hydraulics report Q3943 (2006).

[32] Wosten, JHM, AB Ismail, and ALM van Wijk. 1997. Peat subsidence and its practical implications: a case study in Malaysia. Geoderma 78: 25-36.

$$t\wedge = \frac{D_{peat} \cdot 100}{4.5} \qquad \textbf{(58)}$$

where:

$t\wedge$ = number of years of peat emissions due to continued drainage; years
D_{peat} = average depth of peat in project area; meters

As an example, assuming a project lifetime of 30 years, if peat in the project area exceeds 1.5 meters in depth, the time dimension of peat drainage can be disregarded because the result of Equation 58 indicates that emissions from drainage would continue for more than 30 years. On the other hand, if peat depth in the project area was only 1 meter and baseline drainage emissions begin in Year 1 of the project, then drainage emissions would continue until Year 22 of the project, after which the available peat supply would be exhausted and no additional CO_2 emissions would occur. Thus if $t\wedge$ is greater than the number of years in the project, then drainage shall be included in baseline calculations for every year after the original drainage event. However, if $t\wedge$ is less than the number of years in the project, then drainage emissions shall be calculated only for the number of years in which there would be an available supply of peat to undergo oxidation.

5.3.1.3 Area of peat drainage

It is assumed that the area of peat drained each year in the baseline scenario will be equal to the area cleared and planted for the new land use, i.e., the annual rate of clearing $A_{B,it}^{cleared}$. Once drained, emissions continue in subsequent years until $t\wedge$ is reached, such that drainage emissions are cumulative as new areas are cleared over time. Areas outside the project boundary may be impacted by drainage activities inside the project boundary in the baseline case, but these areas are conservatively ignored.

For example, if the annual rate of clearing $A_{B,it}^{cleared}$ for a 2,500 ha planned plantation in the baseline is 500 ha for the first five years, then the area impacted by drainage ($A_{B,drain,it}$) in Eq. 56 would be 500 ha in Year 1, 1,000 ha in Year 2, 1,500 ha in Year 3, 2,000 ha in Year 4 and 2,500 ha in Year 5. After initial clearing, the area of peat impacted by drainage would be equal to the total area of planned land use conversion (2,500 ha) in subsequent years until $t\wedge$ is reached.

5.3.1.4 Relationship between CO_2 emissions and drainage depth (Eq. 57)

It is known that the function that relates annual GHG emissions to peat drainage depth should be non-linear. Given a lack of extensive field data available for tropical peat forests, projects with no data should apply a linear relationship derived from a compilation of field measurements collected throughout peatlands of Southeast Asia[33,34] where $ME_{B,dd,it}$ = 0.91* $D_{B,,drain,it}$ (or $ME_{B,dd,it}$ = 9 t CO_2 ha^{-1} yr^{-1} for each 10 cm of drainage depth) until additional data become available. It should be noted that this function was parameterized with a range of drainage depth data up to 100 cm (1 meter) only, and should not be extrapolated to predict CO_2 emissions in areas that are expected to be drained >1 meter as per

[33] Hooijer, A., M. Silvius, H. Wösten, S. Page. 2006. PEAT-CO2, Assessment of CO_2 emissions from drained peatlands in SE Asia. Delft Hydraulics report Q3943 (2006).

[34] Couwenberg, J., R. Dommain and H. Joosten (2009). Greenhouse gas fluxes from tropical peatlands in Southeast Asia. Global Change Biology DOI=10.1111/j.1365-2486.2009.02016.x

Applicability Condition F in Section I.3. Improvements to this regression model should be made as new data emerges.

The relationship between drainage depth and CO_2 emissions depends on the water management regime, and subsidence rates have been shown to change over time. When drainage ditches are not maintained and periodically deepened to sustain desired water levels, progressive subsidence leads to increasingly thinner aerobic layers, resulting in reduced rates of peat subsidence and therefore reduced CO_2 emissions. However, tillage, fertilization and root exudates counteract this effect, resulting in continued high oxidative losses in managed agricultural peatlands[35] such as those assumed in the baseline scenario. Therefore, the relationship between drainage depth and baseline CO_2 emissions from drainage as outlined above is assumed to hold throughout the project life or until additional data become available.

5.3.2 Estimation of $E_{B,PeatBurn,it}$ (GHG emissions from peat burning)

After peat drainage occurs, the upper layer of peat is assumed to be intentionally burned along with aboveground biomass when the land is cleared with fire to prepare the site for the new land use. GHG emissions from peat burning as a result of land clearing are estimated (whenever double counting of carbon stock losses is avoided) as follows:

$$E_{B,PeatBurn,it} = E_{B,PeatBurn,CO2,it} + E_{B,PeatBurn,CH4,it} \quad \textbf{(59)}$$

and:

$$E_{B,PeatBurn,CO2,it} = \frac{M_{B,p,it} * EF_{CO_2}}{10^6} \quad \textbf{(60)}$$

$$E_{B,PeatBurn,CH4,it} = \frac{M_{B,p,it} * EF_{CH_4}}{10^6} * GWP_{CH_4} \quad \textbf{(61)}$$

$$M_{B,p,it} = D_{B,burn,it} * A_{B,burn,it} * 10000 * BD_i \quad \textbf{(62)}$$

where:

$E_{B,PeatBurn,it}$	= Total increase in CO_2-e emissions as a result of peat burning under the baseline scenario in stratum *i*, time *t*; t CO_2e
$E_{B,PeatBurn,CO2,it}$	= total CO_2 emissions from peat burning under the baseline scenario in stratum *i*, time *t*; t CO_2e
$E_{B,PeatBurn,CH4,it}$	= total CH_4 emissions from peat burning under the baseline scenario in stratum *i*, time *t*; t CO_2e
$M_{B,p,it}$	= mass of peat burned under the baseline scenario in stratum *i*, time *t*; tons
EF_{CO2}	= CO_2 emissions from the combustion of peat, g CO_2 (t peat)$^{-1}$
EF_{CH4}	= CH_4 emissions from the combustion of peat, g CH_4 (t peat)$^{-1}$
GWP_{CH4}	= Global Warming Potential for CH_4 (IPCC default = 21 for the first commitment period); t CO_2-e. (t CH_4)$^{-1}$

[35] Couwenberg, J., R. Dommain and H. Joosten. 2009. Greenhouse gas fluxes from tropical peatlands in south-east Asia. Global Change Biology, in press. DOI: 10.1111/j.1365-2486.2009.02016.x

$D_{B,burn,it}$	= depth of peat burned under the baseline scenario in stratum *i* at time *t*; meters
$A_{B,,burn,it}$	= area of peat burned under the baseline scenario in stratum *i* at time *t*; ha
BD_i	= bulk density of peat in stratum *i* (g cm^{-3} = t m^{-3})
10000	= scaling factor from ha to square meters; dimensionless

5.3.2.1 Estimation of peat depth burned ($D_{B,burn,it}$)

Single fire events in human-induced fires in southeast Asian peatlands have resulted in losses up to well over one meter of peat[36,37,38]. In the baseline, it is assumed that peat would be burned along with remaining vegetation after drainage in order to clear the land for the new land use. The depth to which peat is drained before burning is defined in Section II.5.3.1.1 above and will determine the depth of peat that would be susceptible to burning.

Based on available measurement data, the mean rate of fire-related peat loss during land clearing should be estimated *ex ante* for all strata using the most up-to-date information as reported in the literature. At present, Couwenberg et al. (2009)[39] summarize burn depth measurements from six studies in SE Asia and report a mean burn depth of 34 cm. The depth of peat burned shall be assumed to be equal to the drainage depth (in cm) minus a critical threshold value of 40 cm above the drainage depth. The rationale to this assumption is that the layer of peat 40 cm directly above the lowered water table is too wet to burn due to capillary rise of water in the pore spaces of the peat. The maximum depth of peat burnt shall not exceed 34 cm. If the difference between drainage depth and the critical threshold exceeds 34 cm, then the maximum burn depth of 34 cm shall be applied. For example, if drainage depth is 80 cm, then the calculation would be 80 cm – 40 cm = 40 cm, which is greater than 34 cm, therefore the burn depth is assumed to be 34 cm. If drainage depth is less than or equal to 40 cm, then burn depth = 0 and there are no emissions from fire associated with land clearing activities. These default values shall be applied until additional data become available or until measurements can be made by the project developer in proxy areas of land use change. (Methods for measuring burn depth in proxy areas are outlined in Section III.5.3.2 of the monitoring methodology below.)

5.3.2.2 Estimation of area of peat burned under the baseline scenario ($A_{B,,burn,it}$)

It is assumed that the area of peat burned in the baseline scenario will be equal to the total area cleared for the new land use. Areas outside the plantation boundary may have burned in the baseline case, but these areas are conservatively ignored. Therefore the area burned per year $A_{B,,burn,it}$ shall be equal to the annual rate of clearing $A_{B,it}^{cleared}$

5.3.2.3 Estimation of peat bulk density (BD_i)

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[36]Page, SE, JO Rieley, H-DV Boehm, F. Siegert, N. Muhamad. 2000. Impact of the 1997 fires on the peatlands of Central Kalimantan, Indonesia. In: Sustaining our Peatlands. Proceedings of the 11th International Peat Congress, 06-12.08.2000, Quebec (eds Rochefort L, Daigle J-Y), pp. 962-970. Canadian Society for Peat and Peatlands, Edmonton.

[37]Page, SE, F Siegert, JO Rieley, H-DV Boehm, A Jaya, S Limin. 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997. Nature 420: 61-65.

[38] Limin, S, A Jaya, F Siegert, JO Rieley, SE Page, H-DV Boehm. 2004. Tropical peat and forest fire in 2002 in Central Kalimantan, its characteristics and the amount of carbon released. In: Wise Use of Peatlands – Proceedings of the 12th International Peat Congress, 6-11 June 2004, Tampere, Volume 1 Oral Presentations (ed Päivänen J), pp. 679-686. International Peat Society, Jyväskylä.

[39] Couwenberg, J., R. Dommain and H. Joosten. 2009. Greenhouse gas fluxes from tropical peatlands in south-east Asia. Global Change Biology, in press. DOI: 10.1111/j.1365-2486.2009.02016.x

Measurements of peat bulk density should be taken across each stratum within the project boundary. Determining the locations and distribution of samples should be determined prior to field work and can follow the sampling strategy outlined in Section 2 above for constructing a peat depth map.

Peat bulk density can be measured using either specialized peat samplers or standard soil bulk density cylinders. All vegetation and litter should be removed before sampling occurs. The soil corer/probe is inserted steadily to a standard depth (e.g., 30 cm). If the probe will not penetrate to the full depth, it is likely that woody material is blocking its route and therefore the core should be inserted in a new location. If the depth of peat at the sampling point is less than the standard depth measured, then the depth of the peat sampled shall be recorded. Sampling to 30-50 cm depth is appropriate because it is the top layer of peat that would be disturbed under the baseline scenario. The volume of the corer should be calculated based on the dimensions of the corer. Peat should be extracted from the probe and placed into a cloth bag with a unique identification number. To reduce variability, sampling is repeated for a total of five locations per sampling point. Dry bulk density samples in an oven at 105 ºC for a minimum of 48 hours then weigh. Peat bulk density should be measured and calculated separately for each stratum. One value can be used if mean values do not differ significantly across strata.

If peat bulk density measurements are made *ex post* rather than *ex ante*, literature values can be used to estimate peat bulk density values *ex ante*. Couwenberg et al. (2009) summarized bulk density values measured in tropical peatlands and reported a mean value of 0.14 g cm^{-3} (Table 2). Another review of bulk density values for surface peat (i.e., the top ≤ 34 cm that is burned in the baseline scenario) yields a similar value of 0.14 g cm^{-3} as the lower bound of the range (Table 3). Therefore, this value of 0.14 can be used in *ex ante* baseline calculations but should be replaced with *ex post* measurements taken from within the project area once these data become available.

Table 2. Bulk density values for tropical peat. From Couwenberg et al. (2009)

Reference	Bulk Density (g cm^{-3})
Page et al. 2002[40]	0.100
Limin et al. 2004[41]	0.160 (0.100-0.220)
Saharjo and Munoz 2005[42]	0.155 (0.060-0.220)
Mean	**0.144**

[40] Page, SE, F. Siegert, JO Rieley, H-DV Boehm, A. Jaya, S. Limin (2002). The amount of carbon released from peat and forest fires in Indonesia during 1997. Nature 420: 61-65. Bulk density data from Neuzil, SG. 1997. Onset and rate of peat and carbon accumulation in four domed ombrogenous peat deposits, Indonesia. In: Biodiversity and sustainability of tropical peatlands (eds Rieley JO and SE Page), pp. 55-72. Samara Publishing, Cardigan.

[41] Limin, S., A Jaya, F Siegert, JO Rieley, SE Page, H-DV Boehm (2004). Tropical peat and forest fire in 2002 in Central Kalimantan, its characteristics and the amount of carbon released. In: Wise Use of Peatlands – Proceedings of the 12th International Peat Congress, 6-11 June 2004, Tampere, Volume 1 Oral Presentations (ed Paivanen J), pp. 679-686. International Peat Society, Jyväskylä.

[42] Saharjo, BH and CP Munoz. 2005. Controlled burning in peat lands owned by small farmers: a case study in land preparation. Wetlands Ecology and Management 13: 105-110.

Table 3. Bulk density values for tropical peat (surface values) in Indonesia. **modified from Page, S.E., Banks, C.J. & Rieley, J.O. Extent and global significance of tropical peat carbon pools. Global Change Biology (submitted – in review)**

Study	Location	Low	High	Midpoint
Andriesse 1974	Sarawak	0.09	0.12	0.11
Driessen & Rochima 1976	Durian-Rasau, West Kalimantan	0.08	0.23	0.16
Driessen & Rochima 1976	Sebangau, Central Kalimantan	0.11	0.14	0.13
Brady 1997	Sarawak	0.10	0.19	0.15
Kurnain 2002	Central Kalimantan	0.15	0.17	0.16
Sajarwan 2002	Central Kalimantan, 0-50 cm	0.20	0.24	0.22
Drajad et al. 2003	South Kalimantan, 0-25 cm	0.39	0.62	0.51
Adi Jaya 2005	Central Kalimantan, surface	0.10	0.12	0.11
Shimamura & Momose 2007	Sumatra	0.01	0.12	0.07
Melling 2005	Sarawak, surface drained	0.15	0.15	0.15
Sumawinata et al. 2008	Central Kalimantan, surface	0.17	0.17	0.17
Average		**0.14**	**0.21**	**0.17**

5.3.2.4 Estimation of CO_2 and CH_4 emission factors (EF_{CO2}, EF_{CH4})

Muraleedharan et al. (2000)[43] measured direct emissions from the combustion of tropical peat at two temperatures (smouldering stage: 480 ºC and flaming stage: 600 ºC). The most abundant C-containing combustion product was CO_2, followed by CO and CH_4. Emission factors for CO_2 and CH_4 are summarized in Table 4. The emission factors for peat combustion at the lower temperature should be assumed in the *ex ante* baseline estimates, as this results in lower overall GHG emissions (CO_2 + CH_4 reported as CO_2 equivalents) and thus a conservative baseline scenario.

Table 4. Greenhouse gas emissions from the combustion of peat. From Muraleedharan et al. (2000).

Component	Temperature (˚C)	
	480	600
	g (ton peat)$^{-1}$	
CO_2	185,000	149,591
CH_4	5,785	11,338

Explanation/justification (if methodology procedure is not self-explanatory):

6. *Ex ante* actual net avoided GHG emissions

Methodology procedure:

The *ex ante* actual net GHG avoided emissions represent the sum of the baseline GHG emissions within the project boundary, minus the increase in greenhouse gas emissions by sources measured in CO_2 equivalents within the project boundary that are a result of the implementation of a project activity.

[43] Muraleedharan, T.R., M. Radojevic, A. Waugh, and A. Caruana. 2000. Emissions from the combustion of peat: an experimental study. Atmospheric Environment 34: 3033-3035.

The only emissions by sources within the project boundary resulting from the implementation of forest protection activities would be emissions from fossil fuel burning for transport of project staff and forest guards. These emissions are no longer required to be accounted for per CDM EB 22 and 24, thus they are excluded in this proposed methodology. The actual net GHG emissions avoided represent the sum of the baseline GHG emissions within the project boundary.

$$C_{ACTUAL} = C_{BSL} \tag{63}$$

where:

C_{ACTUAL} = actual net greenhouse gas emissions avoided; t CO_2-e
C_{BSL} = sum of the baseline GHG emissions (aboveground and peat); t CO_2-e

Note: In this methodology Eq. 63 is used to estimate actual net GHG emissions avoided for the period of time elapsed between project start (t=1) and the year t=t* being the year for which actual net greenhouse gas emissions avoided are estimated.

Explanation/justification (if methodology procedure is not self-explanatory):

7. Leakage

Methodology procedure:

Leakage (*LK*) represents the increase in GHG emissions by sources which occur outside the project boundary that are measurable and attributable to the project activity. Leakage is assumed to occur as a result of the displacement of economic activities (i.e., planned land use conversion) to areas outside the project that lead to deforestation and land use change, estimated in units of t CO_2-e. Thus, as a result of the project activity, the baseline activity of planned land use change may be temporarily or permanently displaced from within the project boundary to areas outside the project boundary.

Determination of the presence or absence of activity displacement that likely leads to increased GHG emissions shall be done prior to adopting the methods and procedures proposed to measure the activity displacement under this methodology.

Under Applicability Condition H in Section I.3, the parcel(s) of peat swamp forest to be converted to another land use must not contain human settlements (towns, villages, etc.) or any human activities that lead to deforestation such as agriculture or grazing. Thus the only activity displacement considered in this methodology is the shift of pre-project planned activities to outside the project boundary. Activity shifting leakage shall be assessed for five full years beyond the date at which deforestation was projected to occur in the baseline.

No increases in GHG emissions caused by displacement of activities associated with the project are expected and LK = 0 if all pre-project activities are displaced to degraded, non-forest land on mineral soils outside the project boundary that have negligible aboveground carbon stocks and that have been non-forest for at least ten years. Evidence of this displacement shall be presented in the PDD at the time of project verification.

In situations other than that described above, the assessment and quantification of activity displacement and land use change shall be undertaken using the methods outlined below, which have been adapted from the AD Partners draft REDD methodology module for estimating emissions from activity shifting for avoided planned deforestation (*LK-ASP*). The draft module was adapted and re-organized here to incorporate the potential for activity displacement to land cover types that differ from the project's baseline strata (e.g., displacement from peat swamp forest to forest on mineral soils). It should be noted that the AD Partners draft REDD module has not yet been approved by the VCS. If updates to this leakage module take place in the future, the updated, most current version of the module should be re-adapted to assess leakage in this methodology.

(From AD Partners REDD methodology module on activity displacement leakage for planned deforestation – edits reflect responses to first set of CARs by TUV-SUD as well as additional edits)

Baseline agents of deforestation (including private companies or local/national governments) may control multiple parcels of forest land within the country that could be used to make up for the generation of goods and/or services lost through implementation of the carbon project. In such cases, the project shall demonstrate that the management plans and/or land-use designations of other lands controlled by the baseline agent of deforestation have not materially changed as a result of the planned project (e.g., designating new lands as plantation concessions, increasing harvest rates in lands already managed for plantation products (oil palm, pulpwood, etc.), clearing intact forests for plantation establishment, or increasing fertilizer use to enhance yields) because such changes could lead to reductions in carbon stocks or increases in GHG emissions. At each verification, documentation shall be provided covering the other lands controlled by the baseline agent where leakage could occur, including, at a minimum, their location(s), area and type of existing land use(s), and management plans. It must also be demonstrated that the total area of government permits (for deforestation activities) that have been granted to the baseline agent of deforestation has not increased due to the implementation of project activities.

Where governments currently control the land and the deforestation agents are yet to be determined but will have government sanction, project developers must demonstrate that areas allotted for land conversion through deforestation by Government agencies will not increase due to the potential for REDD projects. The purpose of this requirement is to demonstrate that the incentive of potential REDD projects has not caused Governments to greatly increase their plans for allowed deforestation. The rate of Government land allocation for land conversion via deforestation must be the same (plus or minus 10%) or on the same trajectory (plus or minus 10%) as before November 28, 2005 and in the year of reference for the planned deforestation REDD project. If the rate of allocation differs beyond the stipulation then this leakage methodology may not be used.

Emissions that result from displacement of pre-project activities to areas outside the project boundary are estimated as:

$$LK = \sum_{t=1}^{t*} \sum_{i=1}^{m_{LK}} LKA_{planned,it} * \Delta C_{it} \qquad \textbf{(64)}$$

where:

LK	= Leakage emissions resulting from displacement of economic activities; t CO_2-e
$LKA_{planned,it}$	= The area of activity shifting leakage in stratum *i* at time *t*; ha
ΔC_{it}	= average carbon stock changes and greenhouse gas emissions in all pools in stratum *i*; t CO_2-e ha^{-1}.

i = 1, 2, 3, …m_{LK} leakage strata
t = 1, 2, 3, …t^* years elapsed since the start of the project activity

7.1 Area of activity shifting leakage ($LKA_{planned,it}$)

Considering that pre-project activities may or may not be displaced to areas that are similar to those found in the project area (i.e., activities may or may not be displaced to a baseline stratum), it may necessary to stratify the area of activity displacement for leakage analysis. If the baseline agent of deforestation manages only lands of similar type as fall within the project area, then $m_{BL} = m_{LK}$ (baseline strata = leakage strata). However, if the baseline agent of deforestation manages strata not found within the project boundary, then $m_{BL} > m_{LK}$ (there will be additional strata to include in the leakage analysis). More guidance on stratification is provided in Section II.2 above.

The overall approach for calculating the area of activity shifting leakage is to first calculate the total rate at which deforestation is forecast to occur across all of the land managed by the baseline agent of deforestation, including the baseline projected deforestation within the project boundaries. (If no baseline agent of deforestation is yet identified, the class of deforestation agent shall be determined[44] and the total rate of deforestation by the class of agent shall be used in calculations.) Second, the predicted deforestation rate within the project boundary is subtracted from the total rate, which yields the expected rate of deforestation by the focal agent if no leakage had occurred. Third, the difference between the expected area of deforestation under the no leakage scenario and the observed area of deforestation over each of the first five years after project implementation results in the area of leaked deforestation.

STEP 1: Determine the baseline rate of forest clearance for the deforestation agent

Two options exist for estimating the baseline rate of forest clearance by the deforestation agent:

Option 1.1 Baseline deforestation rate based on historic deforestation average

Under this approach, the baseline annual deforestation rate by the deforestation agent/class of agent is assumed to be equal to the average cleared area during the previous 5 years.

To implement this option, survey the deforestation agent or class of deforestation agent and, if available, examine official records[45] to determine the total area deforested by the deforestation agent or class of deforestation agent within each leakage stratum each year over the previous five years within the country. Where the agent of planned deforestation is a governmental entity, the spatial domain for which the baseline rate of clearance ($WoPR$) is calculated shall be confined to the level at which the government has control over land use decisions and allocations (district, provincial, national, etc.).

$$WoPR_i = \frac{HistHa_i}{5} \quad \textbf{(65)}$$

[44] If the deforestation agent is not yet defined as an organization or corporation and instead governments currently control the land and the exact agents are yet to be determined but will have government sanction, then a "class of deforestation agents" shall be identified. Examples include entities (companies, associations) practicing similar deforestation practices and post deforestation land use practices. Examples include agribusinesses implementing industrial scale agriculture, entities implementing specific legal land use regulation(s), etc.

[45] Official records may include permits for concessions or permits to deforest for agricultural/commercial purposes

Where:

$WoPR_i$ = Rate of deforestation by the baseline agent or most likely class of agent of the planned deforestation in the absence of the project in stratum *i*; ha yr^{-1}

$HistHa_i$ = The number of hectares of forest cleared by the baseline agent of the planned deforestation in the five years prior to project implementation; ha

i = 1, 2, 3, ..., m_{LK} strata in leakage scenario

Where a specific agent has been identified and there is no history of deforestation within a given stratum and no verifiable plans for controlled lands and future-controlled lands, then *WoPR* should be set to the planned baseline rate for the project.

Where only a class of deforestation agent can be identified, official records and/or remotely sensed imagery paired with ground truthing shall be used to define *WoPR*.

Option 1.2: Baseline deforestation rate based on historic deforestation trend

With this approach, the baseline annual deforestation rate by the baseline deforestation agent/class of agent can be estimated by extrapolating the historical annual trend using a linear regression. Survey the deforestation agent or class of deforestation agent and examine official records (which may include permits for concessions or permits to deforest for agricultural/commercial purposes) to determine the total area deforested by the deforestation agent or class of deforestation agent within each leakage stratum each year over the previous five years within the country. To use this option, annual data for a minimum of five years and a maximum of ten years must be used to create linear regression. The results of the analysis must produce a statistically significant regression with a $p<0.05$ and an adjusted R^2 of >0.75, otherwise Option 1.1 ("historical average") must be used. The linear regression is as follows:

$$Tot\_WoPR_{i,t} = (WOPR_i * t) + b \quad \textbf{(66)}$$

Where:

Tot_WoPR_{it} Cumulative area of deforestation by the baseline agent or most likely class of agent of the planned deforestation in the absence of the project in stratum *i* at time *t*; ha

$WoPR_i$ Estimated slope of the linear regression

b Estimated intercept of the regression line; ha

t 1, 2, 3, … $t^{\#}$ years elapsed since the start of the planned deforestation reference period

The annual rate of deforestation by the baseline agent or most likely class of agent of the planned deforestation in the absence of the project in stratum *i* is therefore equal to the slope of the regression line, or $WoPR_i$.

STEP 2: Estimate the new rate of forest clearance by the focal agent of deforestation with project implementation if no leakage is occurring

Subtract the rate of planned baseline deforestation within the project area from the historic rate of deforestation to calculate the new "zero leakage" rate.

$$NewR_{it} = WoPR_i - A_{B,it}^{cleared} \tag{67}$$

Where:

$NewR_{it}$	= New calculated rate of forest clearance in stratum *i* and time *t* by the baseline agent of the planned deforestation where no leakage is occurring; ha yr^{-1}
$WoPR_i$	= Rate of deforestation by the baseline agent of the planned deforestation in stratum *i* in the absence of the project; ha yr^{-1}
$A_{B,it}^{cleared}$	= Area cleared under the baseline scenario for stratum *i*, in time *t*; ha yr^{-1}
i	= 1, 2, 3, …m_{BL} baseline strata
t	= 1, 2, 3, …*t** years elapsed since the start of the project activity

STEP 3: Monitor all areas deforested by baseline agent of deforestation through the years in which planned deforestation was forecast to occur

All areas deforested by the baseline agent or class of agent of deforestation should be monitored through the first five years in which planned deforestation was forecast to occur. Areas of deforestation may be in the project region or anywhere in the host country, but will include only those lands controlled by the deforestation agent or class of deforestation agents. There is no requirement to track international leakage. Where the agent of planned deforestation is a governmental entity, the spatial domain to be monitored shall be confined to the level at which the government has control over land use decisions and allocations (district, provincial, national, etc.).

$$LKA_{planned,it} = A_{defLK,it} - NewR_{it} \tag{68}$$

Where:

$LKA_{planned,it}$	= The area of activity shifting leakage at time *t*; ha
$NewR_{it}$	= New calculated rate of forest clearance by the baseline agent of the planned deforestation where no leakage is occurring; ha yr^{-1}
$A_{defLK,it}$	= The total observed area of deforestation by the baseline agent at time *t*; ha yr^{-1}
t	= 1, 2, 3, …*t** years elapsed since the start of the project activity

If $NewR_{it}$ exceeds $A_{defLK,it}$ (i.e., the rate of deforestation under the no leakage scenario exceeds the actual observed rate), then $LKA_{planned,it}$ should be set as zero, as positive leakage is not considered under the VCS.

7.2 Net carbon stock changes and GHG emissions

ΔC_{it} represents the average carbon stock changes and greenhouse gas emissions in a leakage stratum *i* at time *t*. For those leakage strata that are also included as baseline strata, $\Delta C_{it} = \overline{C}_{B,it}$ (Eq. 3 above).

For those leakage strata that are not present in the baseline case (e.g., non-peat forest), new estimates of average carbon stock changes and GHG emissions will need to be developed (except in the case where activities are displaced to areas with negligible aboveground carbon stocks on mineral soils, in which case *LK*=0). If local or regional estimates for these strata are not available, changes in biomass and soil carbon stocks can be estimated based on the upper uncertainty bound of default values given in the IPCC GPG-LULUCF. The upper bound is used to develop conservative leakage estimates.

Explanation/justification (if methodology procedure is not self-explanatory):

8. *Ex ante* net anthropogenic GHG emissions avoided

Methodology procedure:

The *ex ante* net anthropogenic GHG emissions avoided as a result of stopping baseline activities is the estimated baseline net emissions minus leakage, in t CO_2-e:

$$C_{REDD} = C_{BSL} - LK \quad \textbf{(69)}$$

where:

C_{REDD} = net reduction in emissions from deforestation; t CO_2-e
C_{BSL} = baseline greenhouse gas emissions (Eq. 1); t CO_2-e
LK = leakage (Eq. 63); t CO_2-e

Note: In this methodology Eq. 69 is used to estimate net emissions avoided for the period of time elapsed between project start (t=1) and the year t=t* being the year for which actual net emissions avoided are estimated. This is done because project emissions and leakage are permanent, which requires calculation of their cumulative values since the starting date of the project activity.

9. Uncertainties and conservative approach

Methodology procedure:

Assessment of uncertainties should follow guidance offered by IPCC 2000, IPCC GPG-LULUCF and IPCC AFOLU. Particular examples of assessment of uncertainty related to expert judgement, allometric equations used and method to combine uncertainties are provided below.

Explanation/justification (if methodology procedure is not self-explanatory):

It is recommended that project participants identify key parameters that would significantly influence the accuracy of estimates. Local values that are specific to the project circumstances should then be obtained for these key parameters whenever possible. These values should be based on:

- Data from well-referenced peer-reviewed literature or other well-established published sources; or

- National inventory data or default data from IPCC literature that has, whenever possible and necessary, been checked for consistency against available local data specific to the project circumstances; or
- In the absence of the above sources of information, expert opinion may be used to assist with data selection. Experts will often provide a range of data, as well as a most probable value for the data. The rationale for selecting a particular data value should be briefly noted in the PDD. For any data provided by experts, the PDD shall also record the expert's name, affiliation, and principal qualification as an expert (e.g., that they are a member of a country's national forest inventory technical advisory group) – plus inclusion of a 1-page summary CV for each expert consulted, included in an annex.

In choosing key parameters or making important assumptions based on information that is not specific to the project circumstances, such as in use of default data, project participants should select values that will lead to an accurate estimation of net GHG emissions, taking into account uncertainties. If uncertainty is significant, project participants should choose data such that it tends to underestimate, rather than overestimate, net avoided emissions.

9.1 Uncertainty in expert judgement

Expert judgement usually will consist of a range, perhaps quoted together with a most likely value. Under these circumstances the following rules apply:

- Where experts only provide an upper and a lower limiting value, assume the probability density function is uniform and that the range corresponds to the 90% confidence interval.
- Where experts also provide a most likely value, assume a triangular probability density function using the most likely values as the mode and assuming that the upper and lower limiting values each exclude 5% of the population. The distribution need not be symmetrical.

9.2 Uncertainty in allometric equations

Uncertainty in allometric equations used to estimate tree biomass shall be assessed by testing actual values obtained from site-specific field data against predicted values. If field data were used to develop the allometric equation, then an independent dataset must be used to verify it.

Verification is demonstrated in cases where at least 75% of measured values fall within the 90% prediction intervals of the mean predicted response and show no systematic bias. Provided this is demonstrated, no further quantification of uncertainty in allometric equations is required. If less than 75% of measured values fall within the 90% prediction intervals then a new, site-specific allometric equation must be derived.

9.3 Uncertainty in literature values

All parameter values derived from data reported in the literature should report both the mean and standard deviation. A 90% confidence interval shall be calculated and reported as the uncertainty around the mean value applied.

9.4 Methods to Combine Uncertainties

Estimated carbon stock changes, emissions and removals arising from LULUCF activities have uncertainties associated with area or other activity data, biomass growth rates, expansion factors, peat emission factors and other coefficients. It is assumed that the uncertainties of the various input data estimates are available, either as default values given in Chapters 2, 3 and 4 of IPCC GPG-LULUCF, expert judgement, or estimates based on sound statistical sampling.

The percentage uncertainty on the estimate of certain parameters and data (yield table values, biomass expansion factors, wood density, carbon fraction and other biophysical parameters) can be assessed from the sample standard deviation of measured sample values, using half the 90% confidence interval width divided by the estimated value, i.e[46].

$$U_s(\%) = \frac{\frac{1}{2}(90\% ConfidenceIntervalWidth)}{\mu} * 100 = \frac{\frac{1}{2}(4\sigma)}{\mu} * 100 \quad \textbf{(70)}$$

Where:

U_s = percentage uncertainty on the estimate of the mean parameter value; %
μ = sample mean value of the parameter
σ = sample standard deviation of the parameter

If the default parameters are used, uncertainty will be higher than if locally measured parameters are used, and can be only roughly estimated with expert judgment[47].

The percentage uncertainties on quantities that are the product of several terms are then estimated using the following equation[48]:

$$U_s = \sqrt{U_1^2 + U_2^2 + ...U_n^2} \quad \textbf{(71)}$$

Where:

U_S = percentage uncertainty of product (emission by sources or removal by sinks)
U_i = percentage uncertainties associated with each term of the product (parameters and activity data),i=1,2,…,n

The percentage uncertainty on quantities that are the sum or difference of several terms can be estimated using following simple error propagation equation[49]:

$$U_c = \frac{\sqrt{(U_{s1} * C_{s1})^2 + (U_{s2} * C_{s2})^2 + ...(U_{sn} * C_{sn})^2}}{|C_{s1} + C_{s2} + ...C_{sn}|} \quad \textbf{(72)}$$

Where:

U_c = combined percentage uncertainty; %
U_{si} = percentage uncertainty on each term of the sum or difference; %
C_{si} = mean value of each term of the sum or difference

Both equations assume that there is no significant correlation among emission and removal estimates and that uncertainties are relatively small. However, it still can be used to give approximate results where uncertainties are relatively large.

This methodology can basically reduce uncertainties through proper stratification of the project area into relatively homogenous strata and verifying that the allometric equations used are appropriate for the project area.

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[46] Box 5.2.1 in GPG LULUCF
[47] GPG LULUCF Chapter 5.2 and Chapter 3.2
[48] Equation 5.2.1 in GPG LULUCF
[49] Refers to equation 5.2.2 in GPG LULUCF

10. Data needed for *ex ante* estimations

Data/parameter:	CF
Data unit:	Dimensionless
Used in equations:	6, 31, 35, 37
Description:	Carbon fraction of dry matter
Source of data:	IPCC default
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$A_{B,it}^{\log ged}$
Data unit:	*ha*
Used in equations:	6
Description:	Area of land logged under the baseline scenario for stratum i, in time t
Source of data:	Analysis of remote sensing data and/or legal records and/or survey information for lands owned or controlled or previously owned or controlled by the baseline agent of deforestation
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	p
Data unit:	dimensionless
Used in equations:	7, 50
Description:	percent of harvest industrial roundwood going into long term wood products
Source of data:	Government statistics, FAO, etc.
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	AP
Data unit:	m^2
Used in equations:	11, 33, 39
Description:	Plot area
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	BEF
Data unit:	dimensionless
Used in equations:	9, 35
Description:	biomass expansion factor for conversion of biomass of merchantable volume to above-ground biomass
Source of data:	Literature values
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	ϕ_i

Data unit:	t d.m. m^{-3} merchantable volume
Used in equations:	9, 35
Description:	volume-weighted average wood density
Source of data:	Literature values or field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$PBB_{B,it}$
Data unit:	dimensionless
Used in equations:	14
Description:	average proportion of $C_{B,AC,it}$ burnt under the baseline scenario in stratum *i*, time *t*
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	*CE*
Data unit:	dimensionless
Used in equations:	14, 52
Description:	average biomass combustion efficiency
Source of data:	IPCC default=0.5
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$A_{B,it}^{cleared}$
Data unit:	ha
Used in equations:	3, 15, 67
Description:	Area cleared under the baseline scenario for stratum *i*, in time *t*
Source of data:	Analysis of remote sensing data and/or legal records and/or survey information for lands owned or controlled or previously owned or controlled by the baseline agent of deforestation
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$N/Cratio$
Data unit:	dimensionless
Used in equations:	16, 53
Description:	nitrogen-carbon ratio
Source of data:	IPCC default = 0.01
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	ER_{N2O}
Data unit:	t CO_2-e (t C)$^{-1}$
Used in equations:	16, 53
Description:	emission ratio for N_2O
Source of data:	IPCC default value = 0.007
Measurement procedures: (if any)	

Any comment:	

Data/parameter:	ER_{CH4}
Data unit:	t CO_2-e (t C)$^{-1}$
Used in equations:	17, 54
Description:	emission ratio for CH_4
Source of data:	IPCC default value = 0.012
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	GWP_{N2O}
Data unit:	t CO_2-e (t N_2O)$^{-1}$
Used in equations:	16, 53
Description:	Global Warming Potential for N_2O
Source of data:	(= 310 for the first commitment period
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	GWP_{CH4}
Data unit:	t CO_2-e (t $CH_{4)}$$^{-1}$
Used in equations:	17, 54
Description:	Global Warming Potential for CH_4
Source of data:	(= 21 for the first commitment period)
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$A_{sampleframe}$
Data unit:	m^2
Used in equations:	21
Description:	Area of one sampling frame
Source of data:	Field measurement
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$CF_{non\text{-}tree}$
Data unit:	dimensionless
Used in equations:	20
Description:	Carbon fraction of dominant non-tree vegetation species
Source of data:	Field measurement or literature values
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$MC_{AG,nontree\_sample,sf,,it}$
Data unit:	kg d.m.
Used in equations:	20
Description:	Carbon stock in above ground non-tree vegetation in sample plot *sf*

	in stratum *i* at time *t* from sampling frame method
Source of data:	Field measurement
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	CF_q
Data unit:	t C t^{-1} d.m.
Used in equations:	22
Description:	Carbon fraction of biomass for species *q*
Source of data:	Field measurement or literature value
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	f_q*(vegetation parameters)*
Data unit:	t. d.m. individual^{-1}
Used in equations:	22
Description:	Allometric equation for species *q* linking parameters such as stem count, diameter of crown, height, or others to above-ground biomass of an individual
Source of data:	Field measurement or literature value
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	Ar_i
Data unit:	ha
Used in equations:	23
Description:	Total area of all non-tree allometric method sample plots in stratum *i*
Source of data:	Field measurement
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$MC_{AG\_nontree\_allometric,i,r,t}$
Data unit:	t C
Used in equations:	23
Description:	Aboveground biomass carbon stock in nontree vegetation in sample plot *r* of stratum *i* at time *t* from non-tree allometric sample plots
Source of data:	Field measurement
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	*angle*
Data unit:	degrees
Used in equations:	25, 26, 27
Description:	angle formed between observer's eye and end of farthest observable canopy branch facing each of eight comopass directions or one of two vantage points

Source of data:	Field measurement
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	*dist*
Data unit:	meters
Used in equations:	25, 26, 27
Description:	distance from observer to end of first canopy branch facing each of eight compass directions or from one of two vantage points
Source of data:	Field measurement
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	*dbh*
Data unit:	cm
Used in equations:	25, 26
Description:	diameter at breast height of tree
Source of data:	Field measurement
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	H_{eye}
Data unit:	meters
Used in equations:	27
Description:	height from ground to observer's eye
Source of data:	Field measurement
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	H_{tree}
Data unit:	meters
Used in equations:	27, 28, 30
Description:	height of tree
Source of data:	Field measurement
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$MV_{B,AG\_tree,it}$
Data unit:	m^3 ha^{-1}
Used in equations:	35
Description:	Mean merchantable volume under the baseline scenario in stratum *i* at time *t*
Source of data:	Field measurement
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$A_{it}^{planted}$
Data unit:	ha

Used in equations:	41
Description:	area of biomass growth on future land use in the baseline scenario in stratum *i* at time *t*
Source of data:	Analysis of remote sensing data and/or legal records and/or survey information for lands owned or controlled or previously owned or controlled by the baseline agent of deforestation
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	*slp*
Data unit:	$t\ C\ ha^{-1}\ yr^{-1}$
Used in equations:	43
Description:	slope of regression line of biomass accumulation function
Source of data:	Calculated based on field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	*b*
Data unit:	$t\ C\ ha^{-1}$
Used in equations:	42
Description:	intercept of regression line
Source of data:	Calculated based on field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	age_{peak}
Data unit:	years
Used in equations:	46
Description:	age of stand at peak production
Source of data:	Calculated based on field measurements or literature values
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$A_{Bh,it}^{cleared}$
Data unit:	ha
Used in equations:	49
Description:	Area cleared at harvest *H* under the baseline scenario for stratum *i*, in time *t*
Source of data:	Analysis of remote sensing data and/or legal records and/or survey information for lands owned or controlled or previously owned or controlled by the baseline agent of deforestation
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	*PBH*
Data unit:	dimensionless
Used in equations:	49
Description:	average proportion of aboveground carbon stock removed during harvest *H* under the baseline scenario for stratum *i*, time t
Source of data:	Field measurements or literature data

Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$PBB_{BH,it}$
Data unit:	dimensionless
Used in equations:	52
Description:	average proportion of remaining aboveground carbon stocks burnt at harvest H under the baseline scenario in stratum *i*, time *t*
Source of data:	
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$D_{B,,drain,it}$
Data unit:	cm
Used in equations:	57
Description:	average depth of peat drainage or average depth to water table under the baseline scenario in stratum *i*, time *t*
Source of data:	
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$A_{B,drain,it}$
Data unit:	ha
Used in equations:	56
Description:	area of drainage impact under the baseline scenario in stratum *i*, time *t*
Source of data:	Analysis of remote sensing data and/or legal records and/or survey information for lands owned or controlled or previously owned or controlled by the baseline agent of deforestation
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	D_{peat}
Data unit:	meters
Used in equations:	58
Description:	average depth of peat in project area
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$D_{B,burn,it}$
Data unit:	meters
Used in equations:	62
Description:	depth of peat burned under the baseline scenario in stratum *i* at time *t*;
Source of data:	Literature values or field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$A_{B,,burn,it}$
Data unit:	ha
Used in equations:	62
Description:	area of peat burned under the baseline scenario in stratum *i* at time *t*
Source of data:	Analysis of remote sensing data and/or legal records and/or survey information for lands owned or controlled or previously owned or controlled by the baseline agent of deforestation
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	BD_i
Data unit:	g cm^{-3} = t m^{-3}
Used in equations:	62
Description:	bulk density of peat
Source of data:	Field measurements or literature values
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	EF_{CO2}
Data unit:	g CO_2 (t peat)$^{-1}$
Used in equations:	60
Description:	CO_2 emissions from the combustion of peat
Source of data:	Literature value
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	EF_{CH4}
Data unit:	g CH_4 (t peat)$^{-1}$
Used in equations:	61
Description:	CH_4 emissions from the combustion of peat
Source of data:	Literature value
Measurement procedures: (if any)	
Any comment:	

11. Other information

Section III: Monitoring methodology description

The methodology outlines the methods for monitoring land use change, forest degradation and carbon pools and forms the basis for implementing the monitoring plan. It facilitates the monitoring of project activities, and serves as reference for monitoring, reporting, and verification required for evaluating project performance, and to support the accurate determination of carbon offsets by project activities.

The methodology was designed so that all necessary field measurements (including measurements of baseline carbon stocks) can be performed up front - prior to project implementation – if desired, thus limiting monitoring activities over the crediting period to monitoring activity data only (area changes).

1. Monitoring of project implementation

Methodology procedure:

The proposed new methodology proposes methods for monitoring the following elements:

- The proposed project activity including the project boundary, a buffer region surrounding the project boundary to ensure against impacts of outside drainage activities, and all activities that result in increased GHG emissions inside the project boundary;
- Actual net GHG emissions including changes in carbon stocks in above-ground biomass, peat emissions
- Leakage due to displacement of economic activities
- A Quality Assurance/Quality Control plan, including field measurements, data collection verification, data entry and archiving, as an integral part of the monitoring plan of the proposed project activity, to ensure the integrity of data collected.

a. Monitoring of the boundary of the proposed project activity

The project boundary delineates the project activity as a distinct land use in relation to the land uses in the adjoining area. Because this methodology is applicable to avoided emissions projects, the project boundary is fixed throughout the entire crediting period. After initial verification of the project boundary using field-based methods, GPS systems and/or remote sensing methods, the project boundary must be monitored over the crediting period to account for emissions associated with any deforestation, illegal logging, peat drainage, or other events that have occurred within the project boundary.

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Monitoring of the project boundary is meant to demonstrate that the actual area where baseline activities were prevented conforms to the area outlined in the project plan. The following monitoring activities are forseen:

- Field (or aerial) surveys concerning the actual project boundary within which baseline activities have been prevented;
- Measuring geographical positions (latitude and longitude of each corner polygon sites) using GPS or remote sensing methods;
- Checking whether the actual boundary is consistent with the description in the PDD;
- If the actual boundary falls outside of the project boundary as defined in the PDD, these lands shall not be accounted as a part of the project activity.

- Input the measured geographical positions into the GIS system and calculate the eligible area of each stratum.

In addition to monitoring the project boundary, if the project boundary does not represent a discrete hydrologic unit (such as a peat dome), then project proponents shall monitor a buffer region directly surrounding the project boundary to ensure that no drainage activities have occurred that could potentially impact peat emissions inside the project boundary. The width of this buffer zone shall be the distance to the edge of the peat dome or 3 km, whichever is the smaller value.

If a buffer zone less than 3 km around the project boundary is to be applied, this value shall be defended in the PDD and methods for monitoring the drainage impacts within the reduced buffer zone shall be designed in consultations with experts in peat hydrology.

b. Monitoring of forest protection activities

As part of monitoring forest protection activities, any increases in GHG emissions that occur within the project boundary after the start of the project must be recorded and deducted from the *ex ante* estimate of baseline emissions. The following categories shall be recorded in the project database and reported at the time of verification:

- Area where natural or anthropogenic disturbances (including fire, illegal logging and other land use change) occurred within the project boundary by date, location, biomass lost or affected, and the preventative or curative measures, if any implemented
- Number and location of logging gaps by date, location, biomass lost or affected, and the preventative or curative measures, if any implemented
- Area and depth of peat burned within the project area by date, location, estimated peat emissions, and the preventative or curative measures, if any implemented
- Area of peat, if any, that was drained within the project boundary by date, location, estimated peat emissions, and the preventative or curative measures, if any implemented
- Information on forest protection practices

Explanation/justification (if methodology procedure is not self-explanatory):

2. Sampling design and stratification

Methodology procedure:

(taken from AR-AM0004)
The number and boundaries of the strata defined *ex ante* using the methodology procedure outlined in Section II.2 may change during the crediting period (*ex post*). For this reason, strata should be monitored periodically. If a change in the number and area of the project strata occurs, the sampling framework should be adjusted accordingly. The methodology procedures for monitoring strata and defining the sampling framework are outlined below.

2.1 Monitoring of strata:

Stratification of the project area into relatively homogeneous units can either increase the measuring precision without increasing the cost unduly, or reduce the cost without reducing measuring precision because of the lower variance within each homogeneous unit.

Project participants should present in the PDD an *ex ante* stratification of the project area using the methods outlined in Section II.2 and build a geo-referenced spatial data base in a GIS platform for each parameter used for stratification of the project area under the baseline and project scenario. This geo-referenced spatial data base should be completed at the earliest stages of the implementation of the project activity. The verifier shall verify the achievement of this stratification and geo-referenced spatial data base at the first verification. The consistency of the actual boundary of the strata as monitored in the field with the description in the PDD shall be periodically monitored, as the boundaries may change during the crediting period due to the following:

- Disturbances (e.g. due to fire or deforestation) may occur that are distributed patchily over a landscape, resulting in different effects on different parts of an originally homogeneous stratum;
- Forest management activities (illegal logging, logging concessions) may occur, resulting in different effects on different parts of an originally homogeneous stratum;
- Two different strata may become similar enough to allow their merging into one stratum.

If one or more of the above conditions occur, *ex post* stratification may be required. The possible need for *ex post* stratification shall be evaluated at each monitoring event and changes in the strata should be reported to the verifier.

Monitoring of strata shall be done using a Geographical Information System (GIS), which allows for the integration of data from different sources (including GPS coordinates and remote sensing data). The monitoring of strata is critical for transparent and verifiable monitoring of the variable A_{it} (area of stratum i at time t), which is of utmost importance for an accurate and precise calculation of net anthropogenic GHG emissions avoided.

2.2 Sampling framework

The sampling framework, including sample size, plot size, plot shape and plot location should be specified in the PDD. The monitoring methodology was designed so that all sampling can involve temporary plots and can occur at the beginning of the project. Thus the only monitoring activity necessary over the crediting period is annual monitoring of land cover change within the project boundary. The number of sample plots is estimated based on accuracy and costs.

The number, size and location of sampling plots shall be determined using the most current version of the CDM Tool "*Calculation of the number of sample plots for measurements within A/R CDM project activities.*"[50]

2.3 Monitoring frequency

Monitoring shall occur annually.

2.4 Measuring and estimating carbon stock changes and peat emissions over time

If a project chooses to track tree growth over time within the project boundary, then the growth of individual trees on permanent plots shall be measured every five years or at each monitoring event depending on the expected GHG stocks and the financial needs of the project activity. The carbon stock changes in the tree pool on each plot are then estimated using the Aerial Imagery Method, the Biomass Expansion Factor method or the Allometric Equations method (as outlined in Section 5.2.2.1 above).

Although monitoring carbon stock increases over time within the project boundary is optional for avoided

[50] http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-03-v2.pdf

emissions projects, monitoring unforeseen carbon stock decreases over time within the project boundary is required. These GHG emissions may be the result of deforestation, degradation, fire, logging, etc. within the project boundary. Monitoring carbon stock changes over the crediting period will allow a deduction to be made to project benefits, if necessary, to account for the actual GHG emissions that occur within the project boundary over the life of the project as well as outside the project boundary in the form of leakage.

Explanation/justification (if methodology procedure is not self-explanatory):

3. Calculation of *ex post* baseline net GHG emissions, if required

Methodology procedure:

Baseline carbon stock changes do not need to be monitored after the project is established, because the accepted baseline approach assumes continuation of existing changes in carbon pools within the project boundary from the time of project validation. However, technical progress and an increase in data availability may occur, allowing for altered baseline estimates.

Explanation/justification (if methodology procedure is not self-explanatory):

4. Data to be collected and archived for the estimation of baseline net GHG emissions

Under this methodology the data needed for estimating baseline GHG emissions are listed in the section II.10 above for calculating *ex ante* baseline net GHG emissions.

5. Calculation of *ex post* actual net GHG emissions avoided

Methodology procedure:

The actual net greenhouse gas emissions avoided represent the sum of the avoided net decreases in carbon stocks and avoided peat emissions within the project boundary (C_{BSL}), minus any GHG emissions from the baseline scenario that are not prevented within the project boundary in the project case (C_{PRJ}), such as logging, fire, or other land use changes that lead to an increase in emissions. The calculations shall be performed annually according to the monitoring plan. Therefore:

$$C_{ACTUAL} = C_{BSL} - C_{PRJ} \quad \textbf{(73)}$$

where:

C_{ACTUAL} = actual net greenhouse gas emissions avoided; t CO_2-e.

C_{BSL} = sum of peat emissions and carbon stock changes in aboveground biomass under the baseline scenario; t CO_2-e

C_{PRJ} = sum of emissions that occur within the project boundary ; t CO_2-e

Note: In this methodology Eq. 73 is used to estimate actual net greenhouse gas emissions avoided for the period of time elapsed between project start (t=1) and the year t=t* being the year for which actual net greenhouse gas avoided emissions are estimated.

5.1 Estimation of baseline emissions (C_{BSL})

Methods for the estimation of baseline emissions (changes in biomass carbon stocks and peat emissions) that would have occurred in the absence of project activities are outlined in Section II.5 and are not repeated here.

5.2 Estimation of emissions occurring during project activities (C_{PRJ})

Monitoring land use change within the project boundary must occur to ensure that any GHG benefits achieved by project activities during the crediting period are real, permanent and secure. Therefore, any decreases in carbon stocks or increases in peat emissions that occur inside the project boundary after the start of the project must be accounted for, including the GHG emissions from any land cover change that may occur within the project area over the crediting period. In theory, project activities that prevent land use change within the project boundary should be 100% successful and E_{it}^{LUC} in Eq. 73 below should be zero. However, emissions from fires and degradation may continue to occur. These emissions shall also be accounted for over the crediting period, along with any unanticipated land use change.

Within the project boundary, three sources of emissions will lead to significant reductions in project benefits: (1) GHG emissions due to selective logging (degradation); (2) GHG emissions due to fire; and (3) GHG emissions due to deforestation:

$$C_{PRJ} = \sum_{t=1}^{t^*} \sum_{i=1}^{m_{PS}} E_{P,it}^{\log ging} + E_{P,it}^{fire} + E_{P,it}^{LUC} \quad \textbf{(74)}$$

where:

C_{PRJ}	= sum of emissions that occur within the project boundary as a result of emissions that were unanticipated and/or unable to be avoided by project activities; t CO_2-e.
$E_{it}^{\log ging}$	= GHG emissions due to logging in stratum *i*, time *t*; t CO_2-e
E_{it}^{fire}	= GHG emissions due to fire in stratum *i*, time *t*; t CO_2-e
E_{it}^{LUC}	= GHG emissions due to land use/cover change in stratum *i*, time *t*; t CO_2-e
i	= 1, 2, 3, ..., m_{PS} strata
t	= 1, 2, 3, ..., t* years

5.2.1 Estimation of GHG emissions due to logging ($E_{it}^{\log ging}$)

The carbon impact of logging is calculated as the difference in carbon stocks between a forest that has been harvested and one that has not. GHG emissions that occur due to logging are a result of changes in live and dead biomass caused by the extraction of timber and damage to residual trees from the logging activities.

The monitoring methodology was designed to enable project participants to estimate an average emission factor per logging gap prior to the start of the project if desired; thus the only monitoring that is necessary over the crediting period is to detect the number of logging gaps and area of new peat drainage present within the project boundary in a given year *t*. Methods for estimating the carbon impacts of logging activities have been documented previously in Pearson et al. (2006)[51] and Brown et al. (2006)[52].

The logging emission factor is estimated to link a readily monitored component (number of logging gaps detected in the monitoring year) with the total aboveground carbon impact. An initial set of ground measurements in logging gaps shall be completed at the beginning of the project or over the life of the project. The size of each gap *k*, the dimensions of the felled tree and commercial log and trees that are severely damaged or killed as a result of the treefall are measured. Steps are outlined below to translate field measurements of logging impacts into an average emission factor per stratum. The area of new canal construction is also monitored to estimate emissions from peat drainage over the monitoring interval.

The GHG emissions attributable to logging within the project boundary over the monitoring period are therefore estimated as:

$$E_{it}^{\log ging} = (N_{P,it}^{gaps} \cdot EF_{\log ging,i}) + E_{drainage,it}^{\log ging} \quad \textbf{(75)}$$

where:

$E_{it}^{\log ging}$	= GHG emissions due to logging in the project area; t CO_2-e
$N_{P,it}^{gaps}$	= number of logging gaps detected in stratum *i*, time t in the project area; dimensionless
$EF_{logging,i}$	= average logging emission factor for stratum *i*; t CO_2-e (logging gap)$^{-1}$
$E_{drainage,it}^{\log ging}$	= CO_2 emissions from peat drainage in stratum *i* at time *t*, t CO_2-e

5.2.1.1 Estimation of $EF_{logging,i}$

An average emission factor ($EF_{logging,i}$) for each stratum can be derived prior to the start of project activities or before the first monitoring event by collecting field measurements in recent logging gaps in the project region. Emission factors for different strata may be similar enough to allow their merging so that one general emission factor value is used. The emission factor for selective logging detected in each stratum *i* can be estimated as:

$$EF_{\log ging,i} = \frac{\sum_{k=1}^{K} C_{P,ik}^{extracted} + C_{P,ik}^{damaged}}{K} \quad \textbf{(76)}$$

where:

[51] Pearson, T., S. Walker, S. Grimland, and S. Brown. 2006. Carbon and co-benefits from sustainable land use management. Deliverable 17: Impact of logging on carbon stocks of forests: The Brazilian Amazon as a case study. Developed for the US Agency for International Development: Winrock International, Arlington, VA. Available at www.winrock.org/Ecosystems/publications.asp?BU=9086

[52] Brown, S., T. Pearson, N. Moore, et al. 2006. Use of aerial digital imagery to measure the impact of selective logging on carbon stocks of tropical forests in the Republic of Congo: Deliverable 9: Aerial imagery analysis of logging damage. Winrock International, Report submitted to USAID. Cooperative Agreement No. EEM-A-00-03-00006-00. Available at www.winrock.org/Ecosystems/publications.asp?BU=9086

$EF_{\log ging}$ = logging emission factor; t CO_2-e (logging gap)$^{-1}$

$C_{P,ik}^{extracted}$ = average carbon extracted as timber per logging gap in stratum *i*; t C

$C_{P,ik}^{damaged}$ = average carbon damaged as a result of logging per logging gap *k* in stratum *i*; t C (gap)$^{-1}$

k = 1, 2, 3, …, *K* logging gaps; dimensionless

To be conservative, all emissions from biomass damaged during timber extraction $C_{P,ik}^{damaged}$ is assumed to be emitted immediately along with $C_{P,ik}^{extracted}$. Carbon storage in wood products is conservatively ignored.

To apply Eq. 75 above, field measurements shall be collected to estimate average values of carbon extracted **(** $C_{P,ik}^{extracted}$ **)** and carbon damaged **(** $C_{P,ik}^{damaged}$ **)** per logging gap *k*. The number of gaps to be measured will depend on the number of gaps available for measurement, accuracy and costs. The number of gaps measured and a summary of logging gap field measurements shall be presented in the PDD.

Steps to estimate the average values of carbon extracted and damaged per logging gap are outlined below.

Step 1. Measure dimensions of the timber tree(s) within each logging gap *k* and estimate average carbon extracted per logging gap ($C_{ik}^{extracted}$ **)**

Step 1a. On each timber tree *tr* in each measured logging gap *k* in each stratum *i*, the following measurements shall be recorded:

1. the diameter at the stump end of each commercial log ($D_{bottom,tr,ik}$)
2. the diameter at the crown end of each commercial log ($D_{top,tr,ik}$)
3. the distance between the stump and crown (length of timber log extracted) ($L_{\log,tr,ik}$)
4. the height of the stump ($H_{s,tr,ik}$)
5. the diameter of the stump ($D_{s,tr,ik}$)
6. the length, top diameter and bottom diameter of any pieces of bole from the timber tree left behind on the forest floor ($L_{piece,tr,ik}$, $D_{piece\text{-}b,tr,ik}$, $D_{piece\text{-}t,tr,ik}$)

Step 1b. Estimate the volume of each extracted log by multiplying log length by the average of the cross-sectional areas at the foot and crown ends of each log:

$$V_{\log,tr,ik} = \frac{1}{3} \cdot L_{\log,tr,ik} \cdot \pi \cdot \left[\left(\frac{D_{bottom,tr,ik}}{200} \right)^2 + \left(\frac{D_{top,tr,ik}}{200} \right)^2 + \left(\frac{D_{bottom,tr,ik}}{200} \cdot \frac{D_{top,tr,ik}}{200} \right) \right] \quad \textbf{(77)}$$

where:

$V_{\log,tr,ik}$ = volume of log extracted from timber tree *tr* in stratum *i*, gap *k*; m^3

$L_{\log,tr,ik}$ = length of log extracted from timber tree *tr* in stratum *i*, gap *k*, measured as the distance from stump to base of crown, less the length of any pieces of bole left on site; m

$D_{bottom,tr,ik}$ = diameter at the stump end of log extracted from timber tree *tr* in stratum *i*, gap *k*, cm

$D_{top,tr,ik}$ = diameter at the crown end of log extracted from timber tree *tr* in stratum *i*, gap *k*, cm

Step 1c. Estimate the biomass carbon of each commercial log by multiplying the estimated volume by the wood density and carbon fraction:

$$C_{\log,tr,ik} = V_{\log,tr,ik} \cdot \phi_i \cdot CF \quad \textbf{(78)}$$

where:

$V_{\log,tr,ik}$	= volume of log extracted from tree *tr* in stratum *i*, gap *k*; m^3
$C_{\log,tr,tk}$	= biomass carbon of log extracted in stratum *i*, gap *k*; t C
ϕ_i	= wood density[53] of extracted log in stratum *i*, t m^{-3}
CF	= carbon fraction of extracted log, IPCC default = 0.5; t C $(t\ d.m.)^{-1}$

Step 1d. Estimate the total biomass carbon and volume of all commercial logs in gap *k*:

$$C_{ik}^{extracted} = \sum_{tr=1}^{TR} C_{\log,tr,ik} \quad \textbf{(79)}$$

where:

$C_{\log,tr,ik}$	= biomass carbon in extracted log of tree *tr* in stratum *i*, gap *k*; t C
$C_{ik}^{extracted}$	= biomass carbon extracted from all trees in stratum *i*, in gap *k*; t C
tr	= 1, 2, 3, …, *TR* timber trees in gap *k*; dimensionless

Step 2. Estimate carbon damage to vegetation as a result of logging ($C_{ik}^{damaged}$)

The total carbon damage caused by logging in each gap *k* is estimated as the sum of the biomass carbon in the crown, stump, any remaining pieces of bole left behind from the felled trees, and the biomass of snapped and uprooted trees:

$$C_{ik}^{damaged} = C_{c+s,ik} + C_{pieces,ik} + C_{incdam,ik} \quad \textbf{(80)}$$

where:

$C_{Damage,ik}$	= total carbon damage caused by logging in stratum *i*, gap *k*; t C
$C_{incdam,ik}$	= incidental carbon damage in stratum *i*, gap *k* due to logged tree; t C
$C_{c+s,ik}$	= biomass carbon in crown and stump of logged tree in stratum *i*, gap *k*; t C
$C_{pieces,ik}$	= biomass carbon in remaining pieces of bole from the timber tree in stratum *i*, gap *k*; t C

Step 2a. Use stump measurements to estimate DBH of the logged tree and calculate total aboveground biomass of the felled timber tree:

[53] A species-specific density is used when the species is identified or a mean tree density can be used if the species was not known.

$$DBH_{tr,ik} = D_{s,tr,ik} - \left[\frac{D_{s,tr,ik} - D_{top,tr,ik}}{L_{\log,tr,ik} \cdot 100} \right] \times (130 - H_{s,tr,ik}) \quad \textbf{(81)}$$

$$B_{AG,tr,ik} = f(DBH_{tr,ik}, H_{tr,ik}) \quad \textbf{(82)}$$

$$C_{AG,tr,ik} = \frac{B_{AG,tr,ik} \cdot CF}{1000} \quad \textbf{(83)}$$

where:

$B_{AG,tr,ik}$	= total aboveground biomass of felled tree *tr* in stratum *i*, gap *k*; kg
$f(DBH_{tr,ik}, H_{tr,ik})$	= an allometric equation linking above-ground tree biomass (kg tree^{-1}) to diameter at breast height (DBH) and possibly tree height (H)
$C_{AG,tr,ik}$	= aboveground biomass carbon of tree *tr* in stratum *i*, gap *k*; t C
$B_{AG,tr,ik}$	= aboveground tree biomass of tree *tr* in stratum *i*, gap *k*; kg
CF	= carbon fraction, t C (t d.m.)$^{-1}$
$D_{s,tr,ik}$	= diameter of the stump of the logged timber tree *tr* in stratum *i*, gap *k* ; cm
$D_{top,tr,ik}$	= diameter at the crown end of log extracted from timber tree *tr* in stratum *i*, gap *k*, cm
$H_{tr,ik}$	= tree height of tree *tr* in stratum *i*, gap *k*; m
$L_{\log,tr,ik}$	= length of log extracted from timber tree *tr* in stratum *i*, gap *k*, measured as the distance from stump to base of crown, less the length of any pieces of bole left on site; m

Step 2b. Estimate the total carbon of all remaining log pieces left at the site:

$$C_{pieces,tr,ik} = \sum_{pce=1}^{PCE} \left[\frac{(0.01 \cdot D_{pce-b,tr,ik}) + (0.01 \cdot D_{pce-t,tr,ik})}{2} \right]^2 \cdot \pi \cdot L_{pce,tr,ik} \cdot \phi_i \cdot CF \quad \textbf{(84)}$$

where:

$C_{pieces,tr,ik}$	= carbon of remaining log pieces left in the logging gap from timber tree *tr* in stratum *i*, gap *k*; t C
$D_{pce-b,tr,ik}$	= diameter of bottom end of piece *pce* left from timber tree *tr* in stratum *i*, gap *k*; cm
$D_{pce-t,tr,ik}$	= diameter of top end of piece *pce* left from timber tree *tr* in stratum *i*, gap *k*; cm
$L_{pce,tr,ik}$	= length of piece *pce* left from timber tree *tr* in stratum *i*, gap *k*, m
ϕ_i	= wood density of piece *pce* left from timber tree *tr* in stratum *i*, gap *k* , t d.m.m^{-3}
CF	= carbon fraction, t C (t d.m.)$^{-1}$
pce	= 1, 2, 3, …, *PCE* pieces

The biomass carbon of the remaining pieces for all logged trees in gap *k* is calculated as:

$$C_{pieces,ik} = \sum_{tr=1}^{TR} C_{pieces,tr,ik} \qquad \textbf{(85)}$$

Step 2c. Estimate carbon in the remaining tree crown and stump by subtracting the biomass of the extracted log and any remaining pieces from the total biomass of the felled tree as calculated in Eq. 107:

$$C_{c+s,tr,ik} = C_{AG,tr,ik} - C_{\log,tr,ik} - C_{pieces,tr,ik} \qquad \textbf{(86)}$$

where:

$C_{c+s,tr,k}$	= biomass carbon in crown and stump of logged tree *tr* in stratum *i*, gap *k*; t C
$C_{AG,tr,ik}$	= aboveground biomass carbon in tree *tr* in stratum *i*, gap *k*; t C
$C_{\log,tr,ik}$	= biomass carbon of log extracted from tree *tr* in stratum *i*, gap *k*, t C
$C_{pieces,tr,ik}$	= biomass carbon of remaining log pieces of tree tr in stratum *i*, gap *k*; t C

The biomass carbon of the remaining tree crown and stumps for all logged trees in gap *k* is calculated as:

$$C_{c+s,ik} = \sum_{tr=1}^{TR} C_{c+s,tr,ik} \qquad \textbf{(87)}$$

where:

$C_{c+s,tr,ik}$	= biomass carbon in crown and stump of logged tree *tr* in stratum *i*, gap *k*; t C
$C_{c+s,ik}$	= biomass carbon in crown and stump of all logged trees in stratum *i*, gap *k*; t C
tr	= 1, 2, 3, …, *TR* timber trees in stratum *i*, gap k; dimensionless

Step 2d. Estimate the incidental damage to surrounding vegetation due to logging:

Damaged trees are those trees in a logging gap *k* that were severely impacted by tree fall. Damage trees are classified as either 1) snapped stem or 2) uprooted. To estimate the amount of damaged vegetation in each gap, the general biomass equation (Eq. 107 above) is applied to measurements of dbh of the damaged trees. Total incidental damage is calculated as:

$$C_{incdam,ik} = \sum_{tr\_d=1}^{TR\_d} C_{AG,tr\_d,ik} \qquad \textbf{(88)}$$

and:

$$C_{AG,tr\_d,ik} = \frac{B_{AG,tr\_d,ik} \cdot CF}{1000} \qquad \textbf{(89)}$$

$$B_{AG,tr\_d,ik} = f(DBH, H) \qquad \textbf{(90)}$$

where:

$C_{incdam,ik}$	= incidental carbon damage in stratum *i*, gap *k* due to logged tree; t C
$C_{AG,tr\_d,ik}$	= aboveground tree biomass carbon of damaged tree *tr_d* in stratum *i*, gap *k*; t C
$B_{AG,tr\_d,ik}$	= aboveground tree biomass of damaged tree *tr_d* in stratum *i*, gap *k*; kg
CF	= carbon fraction, t C (t d.m.)$^{-1}$
$f(DBH, H)$	= an allometric equation linking above-ground tree biomass (kg tree^{-1}) to diameter at breast height (DBH) and possibly tree height (H)
tr_d	= 1, 2, 3, … , *TR_d* damaged trees in stratum *i*, gap *k*, time *t*

5.2.1.2 Estimation of $N_{P,it}^{gaps}$

At each monitoring event, use aerial photographs or other aerial imagery or high resolution remote sensing data to monitor the number of tree gaps present in the project area. Imagery should be collected annually.

At the time the imagery is collected, it is conservative to overestimate the number of gaps by assuming that all gaps are caused by commercial logging and not by natural treefall. The canopy gaps detected during each monitoring event will most likely be from the past year's logging activities; if there is uncertainty about whether a gap was formed during the year the monitoring is taking place or from a previous year, this gap should be included in the count because it is conservative to overestimate the number of trees logged. A minimum gap size threshold shall be determined and documented in the first monitoring year to ensure a standardized count of logging gaps throughout the crediting period.

5.2.1.3 Estimation of $E_{drainage,it}^{logging}$ (GHG emissions from peat caused by canal construction)

If logging takes place within the project area, small canals may be created in the peat to extract logs to major rivers for transport during the wet season. There are difficulties of knowing the distance effect of canal drainage, as this will vary between extremes of dry and wet seasons. Small canals in forest are virtually impossible to detect from space and difficult and time-consuming to find on the ground; most are not linear. There are few data on the distance from these canals that is affected by drainage; more research is needed. The steps outlined below provide a methodology that conservatively estimates the impact of small canals on peat based on current data and scientific understanding, but the methodology should be updated once new and improved data become available.

Step 1. During the first monitoring event, geo-reference all logging gaps as detected in the high resolution imagery collected during the monitoring event.

Step 2. Geo-locate (as GPS points) known exit points for logs that end up on rivers and large canals to be transported off-site.

Step 3. On the ground during the wet season, map the existing network of logging canals by traveling up the canals from the exit points to each georeferenced logging gap, collecting point-specific location information (e.g., GPS points) along the routes taken and following the canal network's non-linearities where they occur to ensure complete coverage.

Step 4. Enter the coordinates of the canals into a GIS and estimate the total length of canals and canal segments.

Step 5. Independently consult with at least two peat experts to estimate conservatively the distance of impact of small, hand-dug canals constructed for logging activities. These estimates shall be estimated from field measurements[54] or output from validated hydrological models. For any data provided by experts, the PDD and/or monitoring reports shall record the expert's name, affiliation, and principal qualification as an expert– plus inclusion of a 1-page summary CV for each expert consulted, included in an annex.

Step 6. In a GIS, construct a buffer width on each side of the canal network mapped in Step 3 that is equal to the conservatively-defined distance of impact determined in Step 5. Calculate the total area of the resulting polygon created in the GIS. This area shall be defined as the area of peat impact ($A_{peatimpact,it}^{\log ging}$) of logging canals in each stratum *i* at time *t*.

Step 7. At each monitoring event, repeat Steps 1-6, estimating the new total area of impact of canals constructed for logging activities. Monitoring canals is conducted at regular (annual) intervals to account for changes in the total length of the canal network due to potential expansion of canals into new areas over time. Once a canal has been created, it is conservative to include this in the network during each monitoring event even if it is no longer active.

Step 8: In the field, measure the average drainage depth along transects perpendicular to the canals. The measurement where the water table is lowest should be assumed to be the depth to which peat is drained across the entire area of impact $A_{peatimpact,it}^{\log ging}$. The sampling plan for estimating average drainage depth shall be outlined in the monitoring report. Improved data shall be applied if and when these data become available. After a drainage depth is defined, estimate average CO_2 emissions per area of drained peat:

$$E_{drainage,it}^{\log ging} = A_{peatimpact,it}^{\log ging} \cdot ME_{dd,it}^{\log ging} \qquad \textbf{(91)}$$

and:

$$ME_{dd,it}^{\log ging} = f(D_{drain,it}^{\log ging}) \qquad \textbf{(92)}$$

where:

$E_{drainage,it}^{\log ging}$	= CO_2 emissions from peat in stratum *i* at time *t*, t CO_2-e
$A_{peatimpact,it}^{\log ging}$	= area of drainage impact in stratum *i*, time *t*; ha
$ME_{dd,it}^{\log ging}$	= mean CO_2 emissions from drained peat in stratum *i*, time *t*; t CO_2/ha
$D_{drain,it}^{\log ging}$	= average depth of peat drainage or average depth to water table in drained area of stratum *i*, time *t* during the dry season; cm

It is known that the function in Eq. 91 should be non-linear. Given a lack of extensive field data available for tropical peat forests, projects with no data should apply a linear relationship derived from a compilation of field measurements collected throughout peatlands of Southeast Asia[55,56] where $ME_{dd,it}$ =

[54] Preliminary field measurements conducted on four transects spanning 150 m on each side of small canals in the Mawas Conservation Project of Central Kalimantan, Indonesia revealed no clear trends between the measured distance from the canal and the average water table depth.

[55] Hooijer, A., M. Silvius, H. Wösten, S. Page. 2006. PEAT-CO2, Assessment of CO_2 emissions from drained peatlands in SE Asia. Delft Hydraulics report Q3943 (2006).

[56] Couwenberg, J., R. Dommain and H. Joosten (2009). Greenhouse gas fluxes from tropical peatlands in Southeast Asia. Global Change Biology DOI=10.1111/j.1365-2486.2009.02016.x

$0.91 \cdot D_{drain,it}^{selective\,\log ging}$ (or $ME_{B,dd,it}$ = 9 t CO_2 ha^{-1} yr^{-1} for each 10 cm of drainage depth) until additional data become available. It should be noted that this function was parameterized with a range of drainage depth data up to 100 cm (1 meter) only, and should not be extrapolated to predict CO_2 emissions in areas that are drained >1 meter.

5.2.2 Estimation of GHG emissions due to fire (E_{it}^{fire})

All fires that occur inside the project boundary must be accounted for over the life of the project, along with the associated GHG emissions resulting from these fires.

The GHG emissions attributable to fires that occur within the project boundary over the monitoring period are therefore estimated as:

$$E_{it}^{fire} = A_{P,burn,it} \cdot EF_{fire,it} \quad \textbf{(93)}$$

where:

E_{it}^{fire}	= GHG emissions due to fire in the project area; t CO_2-e
$A_{p,burn,it}$	= area burned in stratum *i*, time *t* in the project area; ha
$EF_{fire,it}$	= average fire emission factor for stratum *i*, monitoring year *t*; t CO_2-e ha^{-1} burnt

Determination of the presence or absence of burning shall be done prior to adopting the methods and procedures proposed to measure area burnt in the project area under this methodology. Steps are outlined below to estimate the area burnt in each monitoring year and an emission factor per area burnt.

Step 1: **Determine presence/absence of burning and monitor area burnt within project boundary**

Monitoring for fire should occur annually.

At the end of the fire season, determine the presence or absence of burning within the project boundary in a given monitoring year by analyzing medium to high-resolution remote sensing data such as Landsat, SPOT, or other high-resolution remote sensing products (e.g., high resolution aerial digital imagery collected over the project area).

If no fires are detected within the project boundary or within a 1 km buffer zone around the project boundary in the monitoring year, then it is assumed that there were no GHG emissions associated with burning within the project boundary and $E_{it}^{fire} = 0$.

If burned areas are detected within the project boundary or within a 1 km buffer of the project boundary in the monitoring year, then georeferenced, high resolution aerial imagery or georeferenced ground measurements shall be collected over these areas and the location and area of all fire scars shall be calculated and recorded.

Step 2: Estimate an average fire emission factor ($EF_{fire,it}$)

An average emission factor ($EF_{fire,it}$) for each stratum can be derived prior to the start of project activities or before the first monitoring event. Emission factors for different strata or different years may be similar enough to allow their merging so that one general emission factor value is used. This emission factor can be estimated as:

$$EF_{fire,it} = EF_{P,BiomassBurn,it} + EF_{P,PeatBurn,it} \quad \textbf{(94)}$$

where:

$EF_{fire,it}$ = GHG emissions due to fire in the project area within stratum *i*, monitoring year *t*; t CO_2-e ha^{-1} burnt

$EF_{P,BiomassBurn,i}$ = total increase in CO_2-e emissions as a result of aboveground biomass burning in stratum *i*, monitoring year *t*; t CO_2-e ha^{-1} burnt

$EF_{P,PeatBurn,i}$ = total increase in CO_2-e emissions as a result of peat burning in stratum *i*, monitoring year *t;* t CO_2e ha^{-1} burnt

Step 2a. Estimate emission factor for aboveground biomass burning ($EF_{P,BiomassBurn,it}$)

The emission factor for aboveground biomass burning can be estimated as follows:

$$EF_{P,BiomassBurn,it} = EF_{P,BiomassBurn,CO2,it} + EF_{P,BiomassBurn,N2O,it} + EF_{P,BiomassBurn,CH4,it} \quad \textbf{(95)}$$

where:

$EF_{P,BiomassBurn,it}$ = total increase in CO_2-e emissions as a result of aboveground biomass burning in the project case in stratum *i*, monitoring year *t*; t CO_2-e ha^{-1} burnt

$EF_{P,BiomassBurn,CO2,it}$ = CO_2 emission from biomass burning under the project case in stratum *i*, monitoring year *t*; t CO_2-e ha^{-1} burnt

$EF_{P,BiomassBurn,N2O,it}$ = N_2O emission from biomass burning under the project case in stratum *i*, monitoring year *t*; t CO_2-e ha^{-1} burnt

$EF_{P,BiomassBurn,CH4,i}$ = CH_4 emission from biomass burning under the project case in stratum *i*, monitoring year *t*; t CO_2-e ha^{-1} burnt

and:

$$EF_{P,BiomassBurn,CO2,it} = \left(MC_{B,BB,AG,it} \cdot PBB_{P,it} \cdot CE\right)\frac{44}{12} \quad \textbf{(96)}$$

where:

$E_{P,BiomassBurn,CO2,it}$ = CO_2 emission from biomass burning under the project case for stratum *i*, monitoring year *t*; t CO_2-e

$MC_{B,BB,AG,it}$ = average above-ground biomass carbon stock in the baseline scenario for stratum *i*, monitoring year *t*; t C ha^{-1}

$PBB_{P,it}$ = average proportion of $MC_{B,BB,AG,it}$ burnt under the project case for stratum *i*, time *t*; dimensionless

CE = average biomass combustion efficiency (IPCC default=0.5); dimensionless

The CO_2e emissions resulting from a fire are dependent on the proportion of carbon stocks burned (*$PBB_{P,it}$*) and the combustion efficiency (*CE*). The average aboveground carbon stocks of the land cover stratum after a fire can be monitored, otherwise conservative default values can be applied.

The combustion efficiencies CE may be chosen from Table 3.A.14 of IPCC GPG-LULUCF. If no appropriate combustion efficiency can be used, the IPCC default of 0.5 should be used.

Baseline measurements of carbon stocks in unburned areas within stratum *i* can be paired with field measurements within the same stratum in areas where fire occurred during the monitoring event to estimate the proportion of carbon stocks burned:

$$\mathrm{PBB}_{\mathrm{P,it}} = 1 - (MC_{P,AG,it}^{burned} / MC_{B,BB,AG,it}) \quad \textbf{(97)}$$

where:

$PBB_{P,it}$ = average proportion of $MC_{B,BB,AG,it}$ burnt under the project case for stratum *i*, time *t*; dimensionless

$MC_{B,BB,AG,it}$ = estimated aboveground carbon stock in the baseline scenario before burning for stratum *i*, time *t*; t C ha^{-1}

$MC_{P,AG,it}^{burned}$ = estimated aboveground carbon stock after burning under the project case for stratum *i*, time *t*; t C ha^{-1}

If no field measurements are available of carbon stocks in stratum *i* after burning, then the CO_2 emission factor for biomass burning in stratum *i* should be conservatively estimated as the CO_2 equivalent of the mean baseline aboveground carbon stock of the stratum in which fire was detected:

$$EF_{P,BiomassBurn,CO2,i} = MC_{B,BB,AG,it} \cdot \frac{44}{12} \quad \textbf{(98)}$$

where:

$E_{P,BiomassBurn,CO2,i}$ = CO_2 emission from biomass burning under the project case for stratum *i*, monitoring year *t*; t CO_2-e

$MC_{B,AG,it}$ = average above-ground biomass carbon stock in the baseline scenario for stratum *i*, monitoring year *t*; t C ha^{-1}

$\frac{44}{12}$ = ratio of molecular weights of CO_2 and carbon; dimensionless

Non-CO_2 emission factors are calculcated as:

$$EF_{P,BiomassBurn,N2O,it} = EF_{P,BiomassBurn,CO2,it} \cdot \frac{12}{44} \cdot (N/Cratio) \cdot ER_{N_2O} \cdot \frac{44}{28} \cdot GWP_{N_2O} \quad \textbf{(99)}$$

$$EF_{P,BiomassBurn,CH4,it} = EF_{P,BiomassBurn,CO2,it} \cdot \frac{12}{44} \cdot ER_{CH_4} \cdot \frac{16}{12} \cdot GWP_{CH_4} \quad \textbf{(100)}$$

where:

$E_{P,BiomassBurn,CO2,it}$ = CO_2 emission from aboveground biomass burning under the project case in stratum *i*, monitoring year *t*; t CO_2-e.

$E_{P,BiomassBurn,N2O,it}$ = N_2O emission from aboveground biomass burning under the project case in stratum *i*, monitoring year *t*; t CO_2-e

$E_{P,BiomassBurn,CH4,it}$ = CH_4 emission from aboveground biomass burning under the project case in stratum *i*, monitoring year *t*; tCO_2-e

$N/Cratio$ = nitrogen-carbon ratio (IPCC default = 0.01); dimensionless

ER_{N2O} = emission ratio for N_2O (IPCC default value = 0.007); t CO_2-e $(t\ C)^{-1}$

ER_{CH4} = emission ratio for CH_4 (IPCC default value = 0.012); t CO_2-e $(t\ C)^{-1}$

GWP_{N2O} = Global Warming Potential for N_2O (= 310 for the first commitment period); t CO_2-e $(t\ N_2O)^{-1}$

GWP_{CH4} = Global Warming Potential for CH_4 (21 for the first commitment period); t CO_2-e $(t\ CH_{4)})^{-1}$

The nitrogen-carbon ratio (N/C ratio) is approximated to be about 0.01. This is a general default value that applies to leaf litter, but lower values would be appropriate for fuels with greater woody content, if data are available. Emission factors for use with above equations are provided in Tables 3.A.15 and 3.A.16 of IPCC GPG-LULUCF.

Step 2b. Estimate emission factor for peat burning ($EF_{P,PeatBurn,it}$)

An emission factor for peat burning can be estimated as follows:

$$EF_{P,PeatBurn,it} = EF_{P,PeatBurn,CO2,it} + EF_{P,PeatBurn,CH4,it} \quad \textbf{(101)}$$

and:

$$EF_{P,PeatBurn,CO2,it} = \frac{M_{P,peat,it} * EF_{CO_2}}{10^6} \quad \textbf{(102)}$$

$$EF_{P,PeatBurn,CH4,it} = \frac{M_{P,peat,it} * EF_{CH_4}}{10^6} * GWP_{CH_4} \quad \textbf{(103)}$$

$$M_{P,peat,it} = D_{P,burn,it} * 10000 * BD_i \quad \textbf{(104)}$$

where:

$EF_{P,PeatBurn,it}$ = Total increase in CO_2-e emissions as a result of peat burning under the project scenario in stratum *i*, time *t*; t CO_2e

$EF_{P,PeatBurn,CO2,it}$ = total CO_2 emissions from peat burning under the project scenario in stratum *i*, time *t*; t CO_2e

$EF_{P,PeatBurn,CH4,it}$ = total CH_4 emissions from peat burning under the project scenario in stratum *i*, time *t*; t CO_2e

$M_{P,peat,it}$ = mass of peat burned under the project scenario in stratum *i*, time *t*; tons

EF_{CO2} = CO_2 emissions from the combustion of peat, g CO_2/ton peat

EF_{CH4} = CH_4 emissions from the combustion of peat, g CO_2/ton peat

GWP_{CH4}	= Global Warming Potential for CH_4 (IPCC default = 21 for the first commitment period); t CO_2-e. (t CH_4)$^{-1}$
$M_{P,peat,it}$	= total mass of peat burned under the project scenario in stratum I, time t; tons
$D_{P,burn,it}$	= depth of peat burned under the project scenario in stratum *i* at time *t*; meters
BD_i	= bulk density of peat in stratum *i* (g cm^{-3} = t m^{-3})

The depth of peat burned ($D_{P,burn,it}$) per fire shall be measured in the field or conservatively estimated based on literature values[57]. If literature values are used, verification shall be conducted using limited ground sampling to ensure the actual burn depths measured fall within the uncertainty range of the literature value applied. Burn depth can be measured by monitoring active fire fronts within or in the vicinity of the project area and installing sample posts to measure total peat depth before and after burning. Alternative methodologies for measuring the depth of peat burned may also be considered, such as interferometric analysis of land subsidence using radar data, user of airborne lidar, etc. All technologies used shall be described in detail in the PDD and/or monitoring reports. EF_{CO2} and EF_{CH4} shall be estimated using the baseline methodology outlined in Section II.5.3.1.4, Estimation of CO_2 and CH_4 emission factors **(**EF_{CO2}, EF_{CH4}).

Muraleedharan et al. (2000)[58] measured direct emissions from the combustion of tropical peat at two temperatures (smouldering stage: 480 ºC and flaming stage: 600 ºC). The most abundant C-containing combustion product was CO_2, followed by CO and CH_4. Emission factors for CO_2 and CH_4 are summarized in Table 1. The emission factors for peat combustion at the higher temperature should be assumed in the estimates of project emissions, as this results in higher overall GHG emissions (CO_2 + CH_4 reported as CO_2 equivalents) and thus a conservative project scenario.

Table 1. Greenhouse gas emissions from the combustion of peat. From Muraleedharan et al. (2000).

Component	Temperature (˚C)	
	480	600
	g (ton peat)$^{-1}$	
CO_2	185,000	149,591
CH_4	5,785	11,338

5.2.3 Estimation of GHG emissions due to land clearing (deforestation)

The area of land cover change that occurs within the project area that is not due to fire or logging, along with the associated GHG emissions, also must be accounted for at each monitoring event. Monitoring can occur using a variety of remote sensing imagery including georeferenced aerial imagery or other remote sensing imagery such as Landsat or radar imagery verified with field measurements. An accurate land cover map must exist at the start of the project. Medium-resolution remote sensing data or high resolution aerial images shall be collected and processed in each monitoring year to estimate the area of land cover change. This imagery can be the same as was used to detect the area of fire and/or selective logging

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[57] Based on a literature review in Couwenberg et al. (2009), the peat depth burnt in peat fires averages 34 cm across six studies from 1988 to 2002. A conservative value for burn depth would be the upper end of the range reported, which is 55 cm.

[58] Muraleedharan, T.R., M. Radojevic, A. Waugh, and A. Caruana. 2000. Emissions from the combustion of peat: an experimental study. Atmospheric Environment 34: 3033-3035.

within the project boundary. A description of the methods used to detect land cover change shall be included in the PDD.

Monitoring for land cover change should occur annually.

The GHG emissions attributable to deforestation that occur within the project boundary over the monitoring period are therefore estimated as:

$$E_{it}^{LCC} = \sum_{t=1}^{t*} \sum_{i=1}^{m_{PS}} \left(A_{P,LCC,it} \cdot EF_{P,LCC,AG,it} \right) + \left(A_{peatimpact,it}^{LCC} \cdot EF_{peat,drainage,it} \right) \quad \textbf{(105)}$$

where:

E_{it}^{LCC}	= GHG emissions due to land cover change in the project area; t CO_2-e
$A_{P,LCC,it}$	= area that underwent land cover change in stratum *i*, monitoring year *t*; ha
$A_{peatimpact,it}^{LCCn}$	= area of drainage impact due to land cover change in stratum *i*, monitoring year *t*; ha
$EF_{P,LCC,AG,it}$	= average deforestation emission factor for stratum *i*, monitoring year *t*; t CO_2-e ha^{-1}
$EF_{peat,drainage,it}$	= average peat drainage emission factor for stratum *i*, monitoring year *t*; t CO_2-e ha^{-1}

Determination of the presence or absence of deforestation shall be done prior to adopting the methods and procedures proposed to measure area deforested in the project area under this methodology. Steps are outlined below to estimate the area deforested in each monitoring year and an emission factor per area deforested.

Step 1: **Monitor area deforested and area of impact of peat drainage within project boundary**

The location and area of all land cover change shall be calculated and recorded in monitoring year *t* based on georeferenced aerial imagery or other remote sensing data. It is conservative to assume that the area of peat affected by land cover change is equal to 100% of the converted area ($A_{P,LCC,,it}$). If canals are detected in the imagery (e.g. built from a main river to the area of land cover change), then the area of peat affected increases beyond the area of converted land because canals drain additional peat. This increase must be accounted for.

Step 2. Consult with peat experts to estimate conservatively the distance of impact of large canals constructed for activities related to the new land use/land cover. These estimates shall be estimated from field measurements[59], expert opinion or output from validated hydrological models. For any data provided by experts, the PDD shall record the expert's name, affiliation, and principal qualification as an expert– plus inclusion of a 1-page summary CV for each expert consulted, included in an annex.

Step 3. In a GIS, construct a buffer width around the deforested area and all large canals associated with the land use change that is equal to the conservatively-defined distance of impact determined in Step 2.

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[59] Preliminary field measurements conducted on four transects spanning 150 m on each side of small canals in the Mawas Conservation Project of Central Kalimantan, Indonesia revealed no clear trends between the measured distance from the canal and the average water table depth.

Calculate the total area of the resulting polygon created in the GIS. This area is defined as the area of peat impact ($A^{LCC}_{peatimpact,it}$) from land cover change in each stratum *i* at time *t*.

Step 4. At each monitoring event, repeat Steps 1-3, estimating the new area of impact of canals constructed for the new land use/land cover. Monitoring canals is conducted at regular (annual) intervals to account for changes in the total length of the canal network due to potential expansion of canals into new areas over time. Once a canal has been created, it is conservative to include this in the network during each monitoring event even if it is no longer active.

Step 5: In the field, sample the depth of drainage immediately adjacent to the canals and assume that peat is drained to this depth across the entire area of impact. If field measurements are not available, consult with peat experts to conservatively estimate the average depth of peat drainage due to the new land use activities. Improved data of the depth to which peat is drained shall be applied if and when these data become available.

Step 6. Estimate average land cover change emission factors (aboveground and peat) for each stratum. Emission factors associated with decreases in aboveground carbon stocks and peat emissions in the project boundary per hectare of land use change are calculated as:

$$EF_{P,LCC,AG,it} = MC_{B,AG,it} \cdot \frac{44}{12} \quad \textbf{(106)}$$

$$EF_{peat,drainage,it} = ME^{LCC}_{dd,it} \quad \textbf{(107)}$$

and:

$$ME^{LCC}_{dd,it} = f(D^{LCC}_{drain,it}) \quad \textbf{(108)}$$

where:

$EF_{P,LCC,AG,it}$ = average deforestation emission factor for aboveground emissions in stratum *i*, monitoring year *t*; t CO_2-e ha^{-1}

$EF_{peat,drainage,it}$ = average deforestation emission factor for peat drainage in stratum *i*;, monitoring year *t*; t CO_2-e ha^{-1}

$MC_{B,BB,AG,it}$ = estimated above-ground carbon stock in the baseline scenario before burning for stratum *i* at time *t*; t C ha^{-1}

$ME^{LCC}_{dd,it}$ = average peat CO_2 emissions under the project scenario in stratum *i* at time *t* due to land cover change in the project area, t CO_2-e ha^{-1}

$\frac{44}{12}$ = ratio of molecular weights of CO_2 and carbon; dimensionless

$D^{LCC}_{drain,it}$ = average depth of peat drainage or average depth to water table in the deforested area under the project scenario in stratum *i*, time *t*; cm

Carbon stocks of the land cover type after the deforestation occurred can be estimated if desired, but it is conservative in the project case to ignore the accumulation. If increases are to be estimated, permanent sample plots must be installed to measure increases in carbon stocks. See Sec. II 5.2.2.1 ‘Estimation of mean carbon stocks in aboveground tree biomass’ for methods on calculating tree biomass.

It is known that the function in Eq. 95 should be non-linear. Given a lack of extensive field data available for tropical peat forests, projects with no data should apply a linear relationship derived from a compilation of field measurements collected throughout peatlands of Southeast Asia where $ME_{dd,it}$ = $0.91 \cdot D_{drain,it}$ until additional data become available. It should be noted that this function was parameterized with a range of drainage depth data up to 100 cm (1 meter) only, and should not be extrapolated to predict CO_2 emissions in areas that are expected to be drained >1 meter as per the applicability condition in Section I.3.

5.3 Monitoring biomass accumulation in the project area ($\Delta CO_2e_{P,LB}$)

The carbon emissions that were prevented due to project activities were calculated in the baseline case. The existing carbon stocks in the project area were counted as carbon offsets because in the baseline, trees would have been cut down. However, due to project activities, these trees will continue to grow and accumulate biomass.

It is conservative to ignore this biomass accumulation. Per the applicability condition of this methodology, the biomass of vegetation within the project boundary at the start of the project must be at steady-state, or is increasing due to recovery from past disturbance, and so monitoring project GHG removals by herbaceous vegetation can be conservatively neglected if desired. Monitoring biomass accumulation is recommended only where large accumulations are expected to occur.

If the additional carbon that accumulates in this vegetation over the life of the project (that would have been removed in the baseline case) are to be measured, trees must be monitored using permanent sample plots (field plots or aerial imagery plots) installed at the beginning of the project and biomass accumulation in each stratum must be monitored over time. Methods to estimate changes in the litter and dead wood pool are not included in this methodology and are ignored.

See Sec. II 5.1.2 Sampling Framework for methods on determining plot number, size, and location. See Sec. II 5.2.1.1 Estimation of mean carbon stocks in AG tree biomass for methods on collection of mean tree carbon stocks.

Explanation/justification (if methodology procedure is not self-explanatory):

6. Data to be collected and archived for *ex post* actual net GHG emissions avoided

Data/parameter:	$N_{P,it}^{gaps}$
Data unit:	dimensionless
Used in equations:	75
Description:	number of logging gaps detected in stratum *i*, time t in the project area
Source of data:	High-resolution aerial imagery
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$L_{\log,tr,ik}$
Data unit:	m

Used in equations:	77, 81
Description:	length of log extracted from timber tree *tr* in stratum *i*, gap *k*, measured as the distance from stump to base of crown, less the length of any pieces of bole left on site
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$D_{bottom,tr,ik}$
Data unit:	cm
Used in equations:	77
Description:	diameter at the stump end of log extracted from timber tree *tr* in stratum *i*, gap *k*
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$D_{top,tr,ik}$
Data unit:	cm
Used in equations:	77,81
Description:	diameter at the crown end of log extracted from timber tree *tr* in stratum *i*, gap *k*
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	ϕ_i
Data unit:	$t\ m^{-3}$
Used in equations:	78, 84
Description:	wood density[60] of extracted log in stratum *i*
Source of data:	Literature values
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	CF
Data unit:	$t\ C\ (t\ d.m.)^{-1}$
Used in equations:	78
Description:	carbon fraction of extracted log
Source of data:	IPCC default = 0.5
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$D_{s,tr,ik}$

[60] A species-specific density is used when the species is identified or a mean tree density can be used if the species was not known.

Data unit:	cm
Used in equations:	81
Description:	diameter of the stump of the logged timber tree *tr* in stratum *i*, gap *k*
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$H_{tr,ik}$
Data unit:	m
Used in equations:	82
Description:	tree height of tree *tr* in stratum *i*, gap *k*
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$D_{pce-b,tr,ik}$
Data unit:	cm
Used in equations:	84
Description:	diameter of bottom end of piece *pce* left from timber tree *tr* in stratum *i*, gap *k*
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$L_{pce,tr,ik}$
Data unit:	m
Used in equations:	84
Description:	length of piece *pce* left from timber tree *tr* in stratum *i*, gap *k*
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$D_{pce-t,tr,ik}$
Data unit:	cm
Used in equations:	84
Description:	diameter of top end of piece *pce* left from timber tree *tr* in stratum *i*, gap *k*; cm
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$D_{drain,it}^{logging}$
Data unit:	cm
Used in equations:	92

Description:	average depth of peat drainage or average depth to water table in drained area of stratum *i*, time *t* during the dry season
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$A_{peatimpact,it}^{\log ging}$
Data unit:	ha
Used in equations:	91
Description:	area of drainage impact in stratum *i*, time *t*
Source of data:	Calculated in GIS
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	CE
Data unit:	dimensionless
Used in equations:	96
Description:	average biomass combustion efficiency
Source of data:	IPCC default=0.5
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$MC_{P,AG,it}^{burned}$
Data unit:	t C ha^{-1}
Used in equations:	97
Description:	estimated aboveground carbon stock after burning under the project case for stratum *i*, time *t*
Source of data:	Field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$N / Cratio$
Data unit:	dimensionless
Used in equations:	99
Description:	nitrogen-carbon ratio
Source of data:	IPCC default = 0.01
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	ER_{N2O}
Data unit:	t CO_2-e $(t\ C)^{-1}$
Used in equations:	99
Description:	emission ratio for N_2O
Source of data:	IPCC default value = 0.007
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	ER_{CH4}
Data unit:	t CO_2-e (t C)$^{-1}$
Used in equations:	100
Description:	emission ratio for CH_4
Source of data:	IPCC default value = 0.012
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	GWP_{N2O}
Data unit:	t CO_2-e (t N_2O)$^{-1}$
Used in equations:	99
Description:	Global Warming Potential for N_2O
Source of data:	(= 310 for the first commitment period
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	GWP_{CH4}
Data unit:	t CO_2-e (t $CH_{4)}$$^{-1}$
Used in equations:	100,103
Description:	Global Warming Potential for CH_4
Source of data:	(= 21 for the first commitment period)
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$A_{p,burn,it}$
Data unit:	ha
Used in equations:	93
Description:	area burned in stratum *i*, time *t* in the project area
Source of data:	Field measurements or using high resolution digital aerial imagery
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$D_{P,burn,it}$
Data unit:	meters
Used in equations:	104
Description:	depth of peat burned under the project scenario in stratum *i* at time *t*;
Source of data:	Field measurements or conservative literature values
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	BD_i
Data unit:	g cm^{-3} = t m^{-3}
Used in equations:	104
Description:	bulk density of peat in stratum *i*
Source of data:	Field measurements or literature values
Measurement procedures: (if any)	

Any comment:	

Data/parameter:	EF_{CO2}
Data unit:	g CO_2 (t peat)$^{-1}$
Used in equations:	102
Description:	CO_2 emissions from the combustion of peat
Source of data:	Literature values
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	EF_{CH4}
Data unit:	g CH_4 (t peat)$^{-1}$
Used in equations:	103
Description:	CH_4 emissions from the combustion of peat
Source of data:	Literature values
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$A_{P,LCC,it}$
Data unit:	ha
Used in equations:	105
Description:	area that underwent land cover change in stratum *i*, monitoring year *t*;
Source of data:	High resolution digital aerial imagery or field measurements
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$A_{peatimpact,it}^{LCCn}$
Data unit:	ha
Used in equations:	105
Description:	area of drainage impact due to land cover change in stratum *i*, monitoring year *t*
Source of data:	Calculated in a GIS
Measurement procedures: (if any)	
Any comment:	

Data/parameter:	$D_{drain,it}^{LCC}$
Data unit:	cm
Used in equations:	108
Description:	average depth of peat drainage or average depth to water table in the deforested area under the project scenario in stratum *i*, time *t*
Source of data:	Field measurements or estimated from literature values if measurements not available
Measurement procedures: (if any)	
Any comment:	

7. Leakage

Methodology procedure:

Leakage (*LK*) represents the increase in GHG emissions by sources which occur outside the project boundary that are measurable and attributable to the project activity. Leakage is assumed to occur as a result of the displacement of economic activities (i.e., planned land use conversion) to areas outside the project that lead to deforestation and land use change, estimated in units of t CO_2-e. Thus, as a result of the project activity, the baseline activity of planned land use change may be temporarily or permanently displaced from within the project boundary to areas outside the project boundary.

Determination of the presence or absence of activity displacement that likely leads to increased GHG emissions shall be done prior to adopting the methods and procedures proposed to measure the activity displacement under this methodology.

Under Applicability Condition H in Section I.3, the parcel(s) of peat swamp forest to be converted to another land use must not contain human settlements (towns, villages, etc.) or any human activities that lead to deforestation such as agriculture or grazing. Thus the only activity displacement considered in this methodology is the shift of pre-project activities to outside the project boundary. Activity shifting leakage shall be assessed for five full years beyond the date at which deforestation was projected to occur in the baseline.

No increases in GHG emissions caused by displacement of activities associated with the project are expected and $LK = 0$ if all pre-project activities are displaced to degraded, non-forest land on mineral soils outside the project boundary that have negligible aboveground carbon stocks and that have been non-forest for at least ten years. Evidence of this displacement shall be presented in the PDD at the time of project verification.

In situations other than that described above, the assessment and quantification of activity displacement and land use change shall be undertaken using the methods outlined below, which have been adapted from the AD Partners draft REDD methodology module for estimating emissions from activity shifting for avoided planned deforestation (LK-ASP). The draft module was adapted and reorganized here to incorporate the potential for activity displacement to land cover types that differ from the project's baseline strata (e.g., displacement from peat swamp forest to forest on mineral soils). It should be noted that the AD Partners draft REDD module has not yet been approved by the VCS. If updates to this leakage module take place in the future, the updated, most current version of the module should be re-adapted to assess leakage in this methodology.

(From AD Partners REDD methodology module on activity displacement leakage for planned deforestation – edits reflect responses to first set of CARs by TUV-SUD as well as additional edits)

Baseline agents of deforestation (including private companies or local/national governments) may control multiple parcels of forest land within the country that could be used to make up for the generation of goods and/or services lost through implementation of the carbon project. In such cases, the project shall demonstrate that the management plans and/or land-use designations of other lands controlled by the baseline agent of deforestation have not materially changed as a result of the planned project (e.g., designating new lands as plantation concessions, increasing harvest rates in lands already managed for plantation products (oil palm, pulpwood, etc.), clearing intact forests for plantation establishment, or increasing fertilizer use to enhance yields) because such changes could lead to reductions in carbon stocks or increases in GHG emissions. At each verification, documentation shall be provided covering the other lands controlled by the baseline agent where leakage could occur, including, at a minimum, their location(s), area and type of existing land use(s), and management plans. It must also be demonstrated that the total area of government permits (for deforestation activities) that have been granted to the baseline agent of deforestation has not increased due to the implementation of project activities.

Where governments currently control the land and the deforestation agents are yet to be determined but will have government sanction, project developers must demonstrate that areas allotted for land conversion through deforestation by Government agencies will not increase due to the potential for REDD projects. The purpose of this requirement is to demonstrate that the incentive of potential REDD projects has not caused Governments to greatly increase their plans for allowed deforestation. The rate of Government land allocation for land conversion via deforestation must be the same (plus or minus 10%) or on the same trajectory (plus or minus 10%) as before November 28, 2005 and in the year of reference for the planned deforestation REDD project. If the rate of allocation differs beyond the stipulation then this leakage methodology may not be used.

Emissions that result from displacement of pre-project activities to areas outside the project boundary are estimated as:

$$LK = \sum_{t=1}^{t^*} \sum_{i=1}^{m_{LK}} LKA_{planned,it} * \Delta C_{it} \quad \textbf{(109)}$$

where:

LK	= Leakage emissions resulting from displacement of economic activities; t CO_2-e
$LKA_{planned,it}$	= The area of activity shifting leakage in stratum i at time t; ha
ΔC_{it}	= average carbon stock changes and greenhouse gas emissions in all pools in stratum i; t CO_2-e ha^{-1}.
i	= 1, 2, 3, …m_{LK} leakage strata
t	= 1, 2, 3, …t^* years elapsed since the start of the project activity

7.1 Area of activity shifting leakage ($LKA_{planned,it}$)

Considering that pre-project activities may not be displaced to areas that are similar to those found in the project area (i.e., activities are not displaced to a baseline stratum), it may necessary to stratify the area of activity displacement for leakage analysis. More guidance on stratification is provided below, also see Section II.2 on stratification.

The overall approach for calculating the area of activity shifting leakage is to first calculate the total rate at which deforestation is forecast to occur across all of the land managed by the baseline agent of deforestation, including the baseline projected deforestation within the project boundaries. (If no baseline agent of deforestation is yet identified, the class of deforestation agent shall be determined[61] and the total

[61] If the deforestation agent is not yet defined as an organization or corporation and instead governments currently control the land and the exact agents are yet to be determined but will have government sanction, then a “class of deforestation agents” shall be identified. Examples include entities (companies, associations) practicing similar deforestation practices and post deforestation land use practices. Examples include agribusinesses implementing industrial scale agriculture, entities implementing specific legal land use regulation(s), etc.

rate of deforestation by the class of agent shall be used in calculations.) Second, the predicted deforestation rate within the project boundary is subtracted from the total rate, which yields the expected rate of deforestation by the focal agent if no leakage had occurred. Third, the difference between the expected area of deforestation under the no leakage scenario and the observed area of deforestation over each of the first five years after project implementation results in the area of leaked deforestation.

STEP 1: Determine the baseline rate of forest clearance for the deforestation agent

Two options exist for estimating the baseline rate of forest clearance by the deforestation agent:

Option 1.1 Baseline deforestation rate based on historic deforestation average

Under this approach, the baseline annual deforestation rate by the deforestation agent/class of agent is assumed to be equal to the average cleared area during the previous 5 years.

To implement this option, survey the deforestation agent or class of deforestation agent and, if available, examine official records[62] to determine the total area deforested by the deforestation agent or class of deforestation agent within each leakage stratum each year over the previous five years within the country. Where the agent of planned deforestation is a governmental entity, the spatial domain for which the baseline rate of clearance (WoPR) is calculated shall be confined to the level at which the government has control over land use decisions (district, provincial, national, etc.).

$$WoPR_i = \frac{HistHa_i}{5} \quad \textbf{(110)}$$

Where:

$WoPR$ = Rate of deforestation by the baseline agent or most likely class of agent of the planned deforestation in the absence of the project in stratum i; ha yr^{-1}

$HistHa_i$ = The number of hectares of forest cleared by the baseline agent of the planned deforestation in the five years prior to project implementation; ha

i = 1, 2, 3, ..., m_{LK} strata in leakage scenario

Where a specific agent has been identified and there is no history of deforestation within a given stratum and no verifiable plans for controlled lands and future-controlled lands, then WoPR should be set to the planned baseline rate for the project.

Where only a class of deforestation agent can be identified, official records and/or remotely sensed imagery paired with ground truthing shall be used to define WoPR.

Option 1.2: Baseline deforestation rate based on historic deforestation trend

With this approach, the baseline annual deforestation rate by the baseline deforestation agent/class of agent can be estimated by extrapolating the historical annual trend using a linear regression. Survey the deforestation agent or class of deforestation agent and examine official records (which may include permits for concessions or permits to deforest for agricultural/commercial purposes) to determine the total area deforested by the deforestation agent or class of deforestation agent within each leakage stratum each

[62] Official records may include permits for concessions or permits to deforest for agricultural/commercial purposes

year over the previous five years within the country. To use this option, annual data for a minimum of five years and a maximum of ten years must be used to create linear regression. The results of the analysis must produce a statistically significant regression with a $p<0.05$ and an adjusted R^2 of >0.75, otherwise Option 1.1 ("historical average") must be used. The linear regression is as follows:

$$Tot\_WoPR_{i,t} = (WOPR_i * t) + b \quad \mathbf{(111)}$$

Where:

Tot_WoPR_{it}	Cumulative area of deforestation by the baseline agent or most likely class of agent of the planned deforestation in the absence of the project in stratum *i* at time *t*; ha
$WoPR_i$	Estimated slope of the linear regression
b	Estimated intercept of the regression line; ha
t	1, 2, 3, … $t^{\#}$ years elapsed since the start of the planned deforestation reference period

The annual rate of deforestation by the baseline agent or most likely class of agent of the planned deforestation in the absence of the project in stratum *i* is therefore equal to the slope of the regression line, or $WoPR_i$.

STEP 2: Estimate the new rate of forest clearance by the focal agent of deforestation with project implementation if no leakage is occurring

Subtract the rate of planned baseline deforestation within the project area from the historic rate of deforestation to calculate the new "zero leakage" rate.

$$NewR_{it} = WoPR_i - A_{B,it}^{cleared} \quad \mathbf{(112)}$$

Where:

$NewR_{it}$	= New calculated rate of forest clearance in stratum *i* by the baseline agent of the planned deforestation where no leakage is occurring; ha yr^{-1}
$WoPR_i$	= Rate of deforestation by the baseline agent of the planned deforestation in stratum *i* in the absence of the project; ha yr^{-1}
$A_{B,it}^{cleared}$	= Area cleared under the baseline scenario for stratum *i*, in time *t*; ha yr^{-1}
i	= 1, 2, 3, …m_{BL} baseline strata
t	= 1, 2, 3, …*t** years elapsed since the start of the project activity

STEP 3: Monitor all areas deforested by baseline agent of deforestation through the years in which planned deforestation was forecast to occur

All areas deforested by the baseline agent or class of agent of deforestation should be monitored through the first five years in which planned deforestation was forecast to occur. Areas of deforestation may be in the project region or anywhere in the host country, but will include only those lands controlled by the deforestation agent or class of deforestation agents. There is no requirement to track international leakage.

Where the agent of planned deforestation is a governmental entity, the spatial domain to be monitored shall be confined to the level at which the government has control over land use decisions (district, provincial, national, etc.).

$$LKA_{planned,it} = A_{defLK,it} - NewR_{it} \quad \textbf{(113)}$$

Where:

$LKA_{planned,it}$ = The area of activity shifting leakage at time *t*; ha

$NewR_{it}$ = New calculated rate of forest clearance by the baseline agent of the planned deforestation where no leakage is occurring; ha yr^{-1}

$A_{defLK,it}$ = The total observed area of deforestation by the baseline agent at time *t*; ha yr^{-1}

t = 1, 2, 3, …*t** years elapsed since the start of the project activity

If $NewR_{it}$ exceeds $A_{defLK,t}$ (i.e., the rate of deforestation under the no leakage scenario exceeds the actual observed rate), then $LKA_{planned,it}$ should be set as zero, as positive leakage is not considered under the VCS.

7.2 Net carbon stock changes and GHG emissions

ΔC_{it} represents the average carbon stock changes and greenhouse gas emissions in a leakage stratum *i* at time *t*. For those leakage strata that are also included as baseline strata, $\Delta C_{it} = \overline{C}_{B,it}$ (Eq. 3 above).

For those leakage strata that are not present in the baseline case (e.g., non-peat forest), new estimates of average carbon stock changes and GHG emissions will need to be developed (except in the case where activities are displaced to areas with negligible aboveground carbon stocks on mineral soils, in which case *LK*=0). If local or regional estimates for these strata are not available, changes in biomass and soil carbon stocks can be estimated based on the upper uncertainty bound of default values given in the IPCC GPG-LULUCF. The upper bound is used to develop conservative leakage estimates.

Explanation/justification (if methodology procedure is not self-explanatory):

8. Data to be collected and archived for leakage

Data/parameter:	$A_{B,it}^{cleared}$
Data unit:	ha
Used in equations:	
Description:	Average annual area of deforestation by the baseline agent of deforestation for the 5 years prior to project implementation
Source of data:	GPS coordinates and/or remote sensing data and/or legal parcel records
Measurement procedures: (if any)	

Any comment:	

Data/parameter:	$A_{defLK,t}$
Data unit:	ha
Used in equations:	110
Description:	The total area of deforestation by the baseline agent of the planned deforestation at time *t*
Source of data:	Analysis of remote sensing data and/or legal records and/or survey information for lands owned or controlled or previously owned or controlled by the baseline agent of deforestation
Measurement procedures: (if any)	
Any comment:	Legal records will include government permits to deforest including concession licenses

Data/parameter:	*HistHa*
Data unit:	ha
Used in equations:	108
Description:	Average annual area of deforestation by the baseline agent of deforestation for the 5 years prior to project implementation
Source of data:	Analysis of remote sensing data and/or legal records and/or survey information for lands owned or controlled or previously owned or controlled by the baseline agent of deforestation
Measurement procedures: (if any)	
Any comment:	

9. *Ex post* net anthropogenic GHG emissions avoided

Methodology procedure:

The *ex post* net anthropogenic GHG emissions avoided is calculated as the difference between the actual GHG emissions avoided minus leakage, therefore the following general formula can be used to calculate the net anthropogenic GHG emissions avoided by a project activity (C_{REDD}), in t CO_2-e:

$$C_{REDD} = C_{ACTUAL} - LK \qquad \textbf{(114)}$$

Where:

C_{REDD}	= net reduced emissions from deforestation; t CO_2-e
C_{ACTUAL}	= actual net greenhouse gas emissions avoided; t CO_2-e
LK	= leakage; t CO_2-e

Note: In this methodology Eq. 114 is used to estimate net anthropogenic GHG emissions avoided for the period of time elapsed between project start (t=1) and the year t=t*, t* being the year for which actual net greenhouse gas emissions avoided are estimated. This is done because project emissions and leakage are permanent, which requires to calculate their cumulative values since the starting date of the project activity.

Calculation of VCUs

To estimate the amount of VCUs that can be issued at time $t^*=t_2$ (the date of verification) for the monitoring period $T = t_2 - t_1$, this methodology uses the following equation:

$$VCUs = (C_{REDD,t2} - C_{REDD,t1}) - BRR - ML \qquad \textbf{(115)}$$

Where:

$VCUs$	Number of Voluntary Carbon Units
$C_{REDD,t2}$	Net anthropogenic greenhouse gas emissions avoided, as estimated for $t^*=t2$; t CO_2-e
$C_{REDD,t1}$	Net anthropogenic greenhouse gas emissions avoided, as estimated for $t^*=t1$; t CO_2-e
BRR	Portion of carbon credits to be withheld as a buffer reserve
ML	Portion of carbon credits to be deducted as market leakage

Buffer reserve should be calculated using *VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination*[63].

[63] Available at: http://www.v-c-s.org/docs/Tool%20for%20AFOLU%20Non-Permanence%20Risk%20Analysis%20and%20Buffer%20Determination.pdf

REDD market leakage assessment conducted at first VCU issuance (whether using default discounts as outlined in VCS Guidelines or project specific analysis(es) shall be subject to the VCS double approval process. REDD market leakage assessments conducted at validation stage and at verification other than the first VCU issuance are not required to undergo the double approval process.

10. Uncertainties and conservative approach

Methodology procedure:

See Chapter 11.2. 'Quality control (QC) and quality assurance (QA) procedures to be applied to the monitoring process.

Explanation/justification (if methodology procedure is not self-explanatory):

11. Other information

11.1 Default values used in elaborating the new methodology

CF	= carbon fraction of dry matter (IPCC default = 0.5); t C (t d.m.)$^{-1}$
GWP_{N2O}	= Global Warming Potential for N_2O (IPCC default for the first commitment period = 310 kg); CO_2-e.(kg N_2O)$^{-1}$
GWP_{CH4}	= Global Warming Potential for CH_4 (IPCC default for the first commitment period = 21 kg); CO_2-e. (kg CH_4)$^{-1}$
ER_{N2O}	= emission ratio for N_2O in biomass burning (IPCC default = 0.007); t CO_2-e. (t C)$^{-1}$
ER_{CH4}	= emission ratio for CH_4 in biomass burning (IPCC default = 0.012); t CO_2-e. (t C)$^{-1}$
CE	= average combustion efficiency of biomass (IPCC default = 0.5); dimensionless
N/C	= N/C ratio of biomass (IPCC default = 0.01); dimensionless

Sources of values: IPCC, 1996 Guidelines, IPCC GPG-LULUCF, IPCC 2006 AFOLU

Other defaults are listed in relevant sections above, with sources listed as footnotes.

11.2 Quality control (QC) and quality assurance (QA) procedures to be applied to the monitoring process

Quality Control (QC) is a system of routine technical activities, to measure and control the quality of the inventory as it is being developed. The QC system is designed to:

- Provide routine and consistent checks to ensure data integrity, correctness, and completeness;
- Identify and address errors and omissions;
- Document and archive inventory material and record all QC activities.

QC activities include general methods such as accuracy checks on data acquisition and calculations and the use of approved standardized procedures for emission calculations, measurements, estimating uncertainties, archiving information and reporting. Higher tier QC activities include technical reviews of source or sink categories, activity and emission factor data, and methods.

Quality Assurance (QA) activities include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process. Reviews, preferably by independent third parties, should be performed upon a finalized inventory following the implementation of QC procedures. Reviews verify that data quality objectives were met, ensure that the inventory represents the best possible estimates of emissions and sinks given the current state of scientific knowledge and data available, and support the effectiveness of the QC program.

To ensure the net avoided emissions are measured and monitored precisely, credibly, verifiably and transparently, a quality assurance and quality control (QA/QC) procedure shall be implemented, including (1) collection of reliable field measurement; (2) reliable collection and analysis of aerial imagery (if applicable); (3) verification of methods used to collect field data; (4) verification of data entry and analysis techniques; and (5) data maintenance and archiving. If after implementing the QA/QC plan it is found that the targeted precision level is not met, then additional field measurements need to be conducted until the targeted precision level is achieved.

1. Reliable field measurements

Collecting reliable field measurement data is an important step in the quality assurance plan. Persons involving in the field measurement work should be fully trained in the field data collection and data analyses. Standard Operating Procedures (SOPs) for each step of the field measurements shall be developed and adhered to at all times. These SOPs should detail all phases of the field measurements and contain provisions for documentation for verification purposes, so that measurements are comparable over time and can be checked and repeated in a consistent fashion. To ensure the collection of reliable field data,

- Field-team members shall be fully aware of all procedures and the importance of collecting data as accurately as possible;
- Field teams shall install test plots if needed in the field and measure all pertinent components using the SOPs;
- Field measurements shall be checked by a qualified person to correct any errors in techniques;
- A document that shows that these steps have been followed shall be presented as a part of the project documents. The document will list all names of the field team and the project leader will certify that the team is trained;
- Any new staff is adequately trained.

2. Reliable aerial imagery collection and analysis

If collected properly, aerial imagery is a powerful and cost-effective way to estimate carbon stocks remotely.

- A systematic sampling design should be used to select plots for analysis.
- A subset of image plots should be selected randomly and interpreted independently by at least one different analyst.
- Persons involved in the field measurement work should be fully trained in the field data collection and data analyses. Standard Operating Procedures (SOPs) for each step of the imagery collection and analysis shall be developed and adhered to at all times. These SOPs should detail all phases of the field measurements and contain provisions for documentation for verification purposes, so that measurements are comparable over time and can be checked and repeated in a consistent fashion.
- Field-team members shall be fully aware of all procedures and the importance of collecting data as accurately as possible;
- Field teams shall install test plots if needed in the field and measure all pertinent components using the SOPs;

- Virtual measurements shall be checked by a qualified person to correct any errors in techniques;
- A document that shows that these steps have been followed shall be presented as a part of the project documents. The document will list all names of the field team and the project leader will certify that the team is trained;
- Any new staff is adequately trained.

3. Verification of field data collection

To verify that plots have been installed and the measurements taken correctly, 10-20% of plots shall be randomly selected and re-measured independently. Key re-measurement elements include the location of plots, *DBH* and tree height. The re-measurement data shall be compared with the original measurement data. Any deviation between measurement and re-measurement below 5% will be considered tolerable and error above 5%. Any errors found shall be corrected and recorded. Any errors discovered should be expressed as a percentage of all plots that have been rechecked to provide an estimate of the measurement error.

4. Verification of data entry and analysis

Reliable estimation of carbon stock in pools requires proper entry of data into the data analyses spreadsheets. To minimize the possible errors in this process, the entry of both field data and laboratory data shall be reviewed using expert judgment and, where necessary, comparison with independent data to ensure that the data are realistic. Communication between all personnel involved in measuring and analyzing data should be used to resolve any apparent anomalies before the final analysis of the monitoring data is completed. If there are any problems with the monitoring plot data that cannot be resolved, the plot should not be used in the analysis.

5. Data maintenance and archiving

Because of the long-term nature of the CDM-AR project activity, data shall be archived and maintained safely. Data archiving shall take both electronic and paper forms, and copies of all data shall be provided to each project participant. All electronic data and reports shall also be copied on durable media such as CDs and copies of the CDs are stored in multiple locations. The archives shall include:

- Copies of all original field measurement data, laboratory data, data analysis spreadsheet;
- Estimates of the carbon stock changes in all pools and non-CO_2 GHG and corresponding calculation spreadsheets;
- GIS products (including all aerial imagery if applicable);
- Copies of the measuring and monitoring reports.

Table 4: Quality control activities and procedures

QC activity	Procedures
Check that assumptions and criteria for the selection of activity data, emission factors and other estimation parameters are documented.	• Cross-check descriptions of activity data, emission factors and other estimation parameters with information on source and sink categories and ensure that these are properly recorded and archived.
Check for transcription errors in data input and reference.	• Confirm that bibliographical data references are properly cited in the internal documentation • Cross-check a sample of input data from each source category (either measurements or parameters used in calculations) for transcription errors.
Check that emissions and removals	• Reproduce a representative sample of emission or removal

are calculated correctly.	calculations. • Selectively mimic complex model calculations with abbreviated calculations to judge relative accuracy.
Check that parameter and units are correctly recorded and that appropriate conversion factors are used.	• Check that units are properly labeled in calculation sheets. • Check that units are correctly carried through from beginning to end of calculations. • Check that conversion factors are correct. • Check that temporal and spatial adjustment factors are used correctly.
Check the integrity of database files.	• Confirm that the appropriate data processing steps are correctly represented in the database. • Confirm that data relationships are correctly represented in the database. • Ensure that data fields are properly labeled and have the correct design specifications. • Ensure that adequate documentation of database and model structure and operation are archived..
Check for consistency in data between categories.	• Identify parameters (e.g., activity data, and constants) that are common to multiple categories of sources and sinks, and confirm that there is consistency in the values used for these parameters in the emissions calculations.
Check that the movement of inventory data among processing steps is correct	• Check that emission and removal data are correctly aggregated from lower reporting levels to higher reporting levels when preparing summaries. • Check that emission and removal data are correctly transcribed between different intermediate products.
Check that uncertainties in emissions and removals are estimated or calculated correctly.	• Check that qualifications of individuals providing expert judgment for uncertainty estimates are appropriate. • Check that qualifications, assumptions and expert judgments are recorded. Check that calculated uncertainties are complete and calculated correctly. • If necessary, duplicate error calculations on a small sample of the probability distributions used by Monte Carlo analyses.
Undertake review of internal documentation	• Check that there is detailed internal documentation to support the estimates and enable reproduction of the emission and removal and uncertainty estimates. • Check that inventory data, supporting data, and inventory records are archived and stored to facilitate detailed review. • Check integrity of any data archiving arrangements of outside organizations involved in inventory preparation.
Check time series consistency.	• Check for temporal consistency in time series input data for each category of sources and sinks. • Check for consistency in the algorithm/method used for calculations throughout the time series.
Undertake completeness checks.	• Confirm that estimates are reported for all categories of sources and sinks and for all years. • Check that known data gaps that may result in incomplete emissions estimates are documented and treated in a conservative way.

Compare estimates to previous estimates.	• For each category, current inventory estimates should be compared to previous estimates, if available. If there are significant changes or departures from expected trends, re-check estimates and explain the difference.

Section IV: Lists of variables, acronyms and references

1. List of variables used in equations:

See subsections above for lists of variables.

2. List of acronyms used in the methodologies:

Acronym	Description
AR	Afforestation and Reforestation
C	Carbon
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent
CDM	Clean Development Mechanism
CF	Carbon fraction
CH_4	Methane
d.m.	Dry Matter
DBH	Diameter at Breast Height
EB	Executive Board
GHG	Greenhouse Gas
GPG for LULUCF	Good Practice Guidance for Land Use, Land-use Change and Forestry
GIS	Geographical Information System
GPG2000	Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
GPS	Global Positioning System
GWP	Global Warming Potential
H	Tree Height
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use Land-Use Change and Forestry
N_2O	Nitrous Oxide
PDD	Project Design Document
QA	Quality Assurance
QC	Quality Control
REDD	Reducing Emissions from Deforestation and Degradation

3. References:

All references are cited in footnotes.

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