Approved VCS Methodology VM0004

Version 1.0

"Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests"

Sectoral Scope 14

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1. **Sources**

This methodology is based on elements from the following methodologies:

AR-AM0004 (version 1.0)
NMBL_NKCAP_A
AR-AM0007 (version 1.0)
AR-AM0005 (version 1.0)
AD Partners REDD Methodology Module (version 1.0, June 2010)

This methodology refers to the latest approved versions of the following tools:

VCS ―Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities‖
CDM Tool ―Calculation of the number of sample plots for measurements within A/R CDM project activities.‖
VCS Tool for Non-Permanence Risk Analysis and Buffer Determination

No approved methodology was available at the time this methodology was created because these activities were not eligible under the CDM. Although avoided land use conversion was eligible as a REDD activity under the VCS, peat was not currently an eligible carbon pool under the VCS at the time of this methodology validation. 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.

The leakage approach outlined in this methodology was adapted from the most current versions of the leakage modules for “estimation of emissions from activity shifting for avoided planned deforestation” and “estimation of emissions from market effects” as summarized in the Avoided Deforestation Partners REDD Methodological Modules (v. 1.0, June 2010).

2. **Summary Description of the Methodology**

This 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 in tropical peat forest. It 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.

This methodology adopts a baseline approach which accounts for “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 latest version of the VCS “Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities1”.

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1 Available at http://www.v-c-s.org/docs/VCS-Tool-VT0001_Tool-for-Demonstration-and-Assessment-of-Additionality-in-AFOLU-Project-Activities.pdf
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 “Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities”.

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 CO₂ emissions and emission factors.

5. **Additionality** is demonstrated using the latest version of the “Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities” approved by the VCS 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 decreases and peat emissions outside the project boundary, are accounted for activity displacement and market effects.

The methodology also 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 and for emissions that occur due to market effects.

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. However, the baseline is re-assessed/revised every 10 years.

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 and market effects** 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.

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.

### 3. Applicability Conditions

Project activities must satisfy the following conditions in order for the 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 cm².

B. The application of the procedure for determining the baseline scenario in Section 6 leads to the conclusion that baseline approach (c) is the most appropriate choice for determination of the baseline scenario (see Kyoto Protocol Decision 5/CMP.1 paragraph 22).

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.

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F. Peat drainage emissions in the baseline scenario shall be calculated using a net peat drainage depth of no more than one meter.

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 of commercial value above the minimum size class sold in the local timber market.

K. The project boundary shall be hydrologically intact such that the project area is not affected by drainage activities that are occurring 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. The total land area allocated to the deforestation agent for planned deforestation must be shown not to have increased solely for the purpose of eliciting REDD credits.

4. Project Boundary

<table>
<thead>
<tr>
<th>Carbon pools</th>
<th>Selected (answer with Yes or No)</th>
<th>Justification / Explanation of choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above ground tree biomass</td>
<td>Yes</td>
<td>Major carbon pool subject to the project activity</td>
</tr>
<tr>
<td>Aboveground non-tree biomass</td>
<td>Yes</td>
<td>Major carbon pool subject to the project activity</td>
</tr>
<tr>
<td>Belowground biomass</td>
<td>No</td>
<td>It is assumed that belowground biomass is included in the peat component. Additionally, root to shoot ratios for peat swamp forests are</td>
</tr>
</tbody>
</table>
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.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead wood</td>
<td>No</td>
<td>Conservative approach under applicability condition</td>
</tr>
<tr>
<td>Litter</td>
<td>No</td>
<td>Conservative approach under applicability condition</td>
</tr>
<tr>
<td>Peat</td>
<td>Yes</td>
<td>Major carbon pool subject to the project activity</td>
</tr>
<tr>
<td>Soil organic carbon</td>
<td>No</td>
<td>The soil component is included in the peat component.</td>
</tr>
<tr>
<td>Wood Products</td>
<td>Yes</td>
<td>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.</td>
</tr>
</tbody>
</table>

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 provided in digital KML shapefile data format in accordance with VCS guidelines.

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>
<thead>
<tr>
<th>Sources</th>
<th>Gas</th>
<th>Included/excluded</th>
<th>Justification / Explanation of choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burning of aboveground biomass</td>
<td>CO₂</td>
<td>Excluded</td>
<td>However, carbon stock decreases due to burning are accounted as a carbon stock change</td>
</tr>
<tr>
<td></td>
<td>CH₄</td>
<td>Included</td>
<td>Non-CO₂ gas emitted from biomass burning</td>
</tr>
<tr>
<td></td>
<td>N₂O</td>
<td>Included</td>
<td>Non-CO₂ gas emitted from biomass burning</td>
</tr>
</tbody>
</table>


⁴ 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”.

⁵ Remotely sensed data includes data acquired from earth observation satellites or aerial photographs.

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

<table>
<thead>
<tr>
<th>Gas</th>
<th>Status</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Included</td>
<td>Main gas of this source</td>
</tr>
<tr>
<td>CH₄</td>
<td>Excluded</td>
<td>Drainage has been shown to have a small effect on CH₄ emission budgets⁷; the highest proportional CH₄ flux forms only &lt;0.2% of the CO₂ emissions in drained peat soils⁸,⁹.</td>
</tr>
<tr>
<td>N₂O</td>
<td>Excluded</td>
<td>Potential emission is negligibly small⁹,¹⁰.</td>
</tr>
</tbody>
</table>

Burning of peat

<table>
<thead>
<tr>
<th>Gas</th>
<th>Status</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Included</td>
<td>Emissions are accounted using an emission factor</td>
</tr>
<tr>
<td>CH₄</td>
<td>Included</td>
<td>Non-CO₂ gas emitted from peat burning; emissions are accounted using an emission factor</td>
</tr>
<tr>
<td>N₂O</td>
<td>Excluded</td>
<td>N₂O is not typically a measured trace gas emission from peat burning¹²; potential emission differential between natural and burned peat is negligible¹³.</td>
</tr>
</tbody>
</table>

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.

5. Stratification

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;

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⁹ CH₄ fluxes were calculated as insignificant following the CDM “Tool for testing significance of GHG emissions in A/R CDM project activities”
Step 2 stratifies the project area according to projected project activities into \textit{m} PS strata; Step 3 achieves the final \textit{ex ante} stratification by combining the results of step 2 with ongoing treatment and stratum boundary monitoring; and Step 4 stratifies the area of leakage due to activity displacement into \textit{m} LK strata.

\textbf{Step 1:} Stratification according to pre-existing conditions and baseline projections:
\begin{itemize}
  \item[a)] Define the factors influencing carbon stock changes in carbon pools.
  \item[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.
  \item[c)] Do a preliminary stratification based on the collected information.
  \item[d)] Carry out supplementary sampling for site specifications for each stratum, including as appropriate:
    \begin{itemize}
      \item Existing aboveground carbon stocks or vegetation types
      \item Present and past land tenure and land use;
      \item Baseline land use in the absence of project activity:
      \item Peat depth differences: Stratification of the project area by peat depth is important when depth in parts or all of the project area is \textbf{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.$^{14,15}$ 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.
      \end{itemize}
  \item[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.
  \item[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 e. 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.
\end{itemize}

\textbf{Step 2:} Stratification according to the project activity:
\begin{itemize}
  \item[a)] Define the project activities
\end{itemize}

\textsuperscript{15} 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.
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) 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.

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 5 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.
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 ($Q$).

6. **Procedure for Determining the Baseline Scenario**

The most current version of the VCS “Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities”, approved by the VCS Board should be used to determine the most plausible baseline scenario. As of July 2010, the most current version of the tool can be accessed on the VCS website at [http://www.v-c-s.org/docs/VCS-Tool-VT0001_Tool-for-Demonstration-and-Assessment-of-Additionality-in-AFOLU-Project-Acivities.pdf](http://www.v-c-s.org/docs/VCS-Tool-VT0001_Tool-for-Demonstration-and-Assessment-of-Additionality-in-AFOLU-Project-Acivities.pdf).

7. **Procedure for Demonstrating Additionality**

The most current version of the VCS “Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities”, approved by the VCS Board as shown in Section 6 above, should be used to determine additionality. As of August 2010, the most current version of the tool can be accessed on the VCS website at [http://www.v-c-s.org/docs/VCS-Tool-VT0001_Tool-for-Demonstration-and-Assessment-of-Additionality-in-AFOLU-Project-Acivities.pdf](http://www.v-c-s.org/docs/VCS-Tool-VT0001_Tool-for-Demonstration-and-Assessment-of-Additionality-in-AFOLU-Project-Acivities.pdf).

8. **Baseline Emissions**

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:

\[
C_{BSL} = \sum_{i=1}^{t^*} \sum_{j=1}^{m_{Bj}} C_{Bjit} \tag{1}
\]

and:

\[
C_{Bjit} = \Delta C_{Bjit} + E_{Bjit} \tag{2}
\]

where:

\[C_{BSL}\] = sum of peat emissions and carbon stock changes in aboveground biomass under the baseline scenario; t CO$_2$-e

\[C_{Bjit}\] = 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.

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\[16\] [http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-03-v2.pdf](http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-03-v2.pdf)
\Delta C_{B,AG,it} = \text{sum of carbon stock changes in aboveground biomass under the baseline scenario for stratum } i \text{ at time } t; \ t \text{ CO}_2\text{-e.}

\( E_{B,p,it} \) = Peat GHG emissions under the baseline scenario for stratum \( i \), time \( t \); \ CO_2\text{-e}

\( i = 1, 2, 3, \ldots m_{BL} \text{ baseline strata} \)

\( t = 1, 2, 3, \ldots t^* \text{ years elapsed since the start of the project activity} \)

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.

### 8.1 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:

\[
\Delta C_{B,AG,it} = E_{\text{timber},it} + E_{B,\text{BiomassBur},it} - R_{B,\text{growth},it} + E_{\text{harvest},it}
\]

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 \text{ CO}_2\text{-e}

\( E_{\text{timber},it} \) = sum of carbon stock changes in aboveground biomass due to timber extraction prior to land clearing in stratum \( i \) at time \( t \); \ t \text{ CO}_2\text{-e}

\( E_{B,\text{BiomassBur},it} \) = sum of carbon stock changes in aboveground biomass due to biomass burning for stratum \( i \) at time \( t \) under the baseline scenario; \ t \text{ CO}_2\text{-e}

\( R_{B,\text{growth},it} \) = 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 \text{ CO}_2\text{-e}

\( E_{\text{harvest},it} \) = 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 \text{ CO}_2\text{-e}

### 8.1.1 Estimation of \( E_{\text{timber},it} \) (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:

\[
E_{\text{timber},it} = (C_{B,\text{extracted}} - C_{B,\text{woodprodmax}}) \cdot \frac{44}{12}
\]

\( C_{B,\text{extracted}} \) 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.
\begin{align}
C_{\text{extracted}}^{B_{B_{i,t}}} &= B_{\text{logged}}^{B_{B_{i,t}}} \cdot CF \cdot A_{\text{logged}}^{B_{B_{i,t}}} \\
C_{\text{woodprod}}^{B_{B_{i,t}}} &= C_{\text{extracted}}^{B_{B_{i,t}}} \cdot p
\end{align}

where:

\begin{align*}
C_{\text{extracted}}^{B_{B_{i,t}}} &= \text{carbon stocks from trees extracted under the baseline scenario in stratum } i \text{ at time } t; \ t \text{ C} \\
C_{\text{woodprod}}^{B_{B_{i,t}}} &= \text{carbon stocks moving into long-term wood products under the baseline scenario for stratum } i \text{ at time } t; \ t \text{ C} \\
B_{\text{logged}}^{B_{B_{i,t}}} &= \text{timber biomass logged under the baseline scenario for stratum } i \text{ at time } t; \ t \text{ d.m. ha}^{-1} \\
CF &= \text{carbon fraction of dry matter } (0.5 \text{ t C} / \text{t biomass}); \ \text{dimensionless} \\
A_{\text{logged}}^{B_{B_{i,t}}} &= \text{Area of land logged under the baseline scenario for stratum } i, \text{ in time } t; \ \text{ha} \\
p &= \text{percent of harvest industrial roundwood going into long term wood products}
\end{align*}

Estimation of the area cleared and logged

As per Applicability Condition D in Section 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. This threat must be demonstrated by documentary proof.

The annual area of forest conversion to the proposed land use type \( A_{\text{cleared}}^{B_{B_{i,t}}} \) (and \( A_{\text{logged}}^{B_{B_{i,t}}} \) if applicable) must be estimated. A valid verifiable plan by the agent of deforestation must exist for estimating the rate at which deforestation and/or logging is projected to occur, and this rate shall be used.

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 area logged should be assumed to be equal to the area cleared unless evidence exists of a different rate.

Estimation of biomass logged

The biomass of timber extracted under the baseline scenario \( B_{\text{logged}}^{B_{B_{i,t}}} \) must be estimated in Equation 5. As per Applicability Condition J outlined in section 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. 8.1.2.1 Estimation of \( MC_{B_{B_{i,t}}} \) 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 $MC_{B,AG\_tree,itr}$, 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:

$$PV_{B,itr} = \left(\frac{\sum_{tr=1}^{TR} TV_{B,AG\_tree,itr} \cdot XF}{1000}\right)$$ \hspace{1cm} (7)

$$PB_{B,itr} = PV_{B,itr} \cdot \phi_i \cdot BEF$$ \hspace{1cm} (8)

### Allometric or Aerial Imagery Method:

$$PB_{B,itr} = \left(\frac{\sum_{tr=1}^{TR} TB_{B,tr} \cdot XF}{1000}\right)$$ \hspace{1cm} (9)

$$XF = \frac{10,000}{AP}$$ \hspace{1cm} (10)

where:
- $PV_{B,itr}$ = Plot level volume to be extracted under the baseline scenario in stratum $i$ at time $t$; m$^3$ ha$^{-1}$
- $PB_{B,itr}$ = Plot level biomass to be extracted under the baseline scenario in stratum $i$ at time $t$; t d.m. 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
- $\phi_i$ = 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:

\[ B_{it}^{logged} = \frac{\sum_{pl} PB_{it}}{PL_{it}} \]  

(11)

where:
- \( B_{it}^{logged} \) = timber biomass logged under the baseline scenario for stratum \( i \) at time \( t \); t d.m. ha\(^{-1}\)
- \( PB_{it} \) = 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

### 8.1.2 Estimation of \( E_{B,\text{BiomassBur},it} \) (GHG emissions from biomass burning for land clearing)

As per Applicability Condition C in section 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.

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 8.1.1 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:

\[ E_{B,\text{BiomassBur},it} = E_{B,\text{BiomassBur,CO2},it} + E_{B,\text{BiomassBur,N2O},it} + E_{B,\text{BiomassBur,CH4},it} \]  

(12)

where:
- \( E_{B,\text{BiomassBur},it} \) = 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
- \( E_{B,\text{BiomassBur,CO2},it} \) = CO\(_2\) emission from biomass burning under the baseline scenario in stratum \( i \) at time \( t \); t CO\(_2\)-e
- \( E_{B,\text{BiomassBur,N2O},it} \) = N\(_2\)O emission from biomass burning under the baseline scenario in stratum \( i \) at time \( t \); t CO\(_2\)-e
- \( E_{B,\text{BiomassBur,CH4},it} \) = CH\(_4\) emission from biomass burning under the baseline scenario in stratum \( i \) at time \( t \); t CO\(_2\)-e

and:
\[ E_{B,\text{BiomassBurn,CO}_2,it} = \left( C_{B,AC,it} \cdot PBB_{B,it} \cdot CE \right) \frac{44}{12} \]  

(13)

where:

\[ E_{B,\text{BiomassBurn,CO}_2,it} = \text{CO}_2 \text{ emission from biomass burning under the baseline scenario in stratum } i \text{ at time } t; \text{ t CO}_2\text{-e} \]

\[ C_{B,AC,it} = \text{estimated above-ground biomass carbon stock before burning in the baseline scenario for stratum } i, \text{ time } t; \text{ t C} \text{ (Eq. 14)} \]

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

\[ CE = \text{average biomass combustion efficiency (IPCC default=0.5); dimensionless} \]

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 2.6 of the 2006 IPCC AFOLU Guidelines, which include values for a wider range of vegetation types than values in Table 3.A.14 of IPCC GPG-LULUCF and also give values for both mean and standard deviation. If no appropriate combustion efficiency can be used, the IPCC default of 0.5 should be used.

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:

\[ C_{B,AC,it} = \left[ MC_{B,AG,it} \ast A_{B,it}^{\text{cleared}} \right] - C_{B,it}^{\text{extracted}} \]  

(14)

where:

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

\[ MC_{B,AG,it} = \text{mean carbon stock in above-ground living biomass under the baseline scenario for stratum } i, \text{ time } t; \text{ t C ha}^{-1} \text{ (Eq. 19)} \]

\[ A_{B,it}^{\text{cleared}} = \text{Area cleared under the baseline scenario for stratum } i, \text{ in time } t; \text{ ha} \text{ (Eq. 8)} \]

\[ C_{B,it}^{\text{extracted}} = \text{carbon stocks from trees extracted under the baseline scenario in stratum } i \text{ at time } t; \text{ t C (Eq. 6)} \]

Emissions of non-CO\(_2\) gases are given by:\(^7\)

\[ E_{B,\text{BiomassBurn,N}_2O,it} = E_{B,\text{BiomassBurn,CO}_2,it} \cdot \frac{12}{44} \cdot \left( N / Cratio \right) \cdot ER_{N_2O} \cdot \frac{44}{28} \cdot GWP_{N_2O} \]  

(15)

\(^7\) Refers to Table 5.7 in 1996 Revised IPCC Guideline for LULUCF and Equation 3.2.19 in IPCC GPG-LULUCF
\[
E_{B,\text{BiomassBurn,CH}_4, it} = E_{B,\text{BiomassBurn,CO}_2, it} \cdot \frac{12}{44} \cdot ER_{CH}_4 \cdot \frac{16}{12} \cdot GWP_{CH}_4
\]

where:

- \( E_{B,\text{BiomassBurn,CO}_2, it} \) = CO₂ emission from aboveground biomass burning under the baseline scenario in stratum \( i \), time \( t \); t CO₂-e.
- \( E_{B,\text{BiomassBurn,N}_2O, it} \) = N₂O emission from aboveground biomass burning under the baseline scenario in stratum \( i \), time \( t \); t CO₂-e
- \( E_{B,\text{BiomassBurn,CH}_4, it} \) = CH₄ emission from aboveground biomass burning under the baseline scenario in stratum \( i \), time \( t \); t CO₂-e
- \( N / C \text{Ratio} \) = nitrogen-carbon ratio (IPCC default = 0.01); dimensionless
- \( ER_{N2O} \) = emission ratio for N₂O (IPCC default value = 0.007); t CO₂-e (t C)⁻¹
- \( ER_{CH}_4 \) = emission ratio for CH₄ (IPCC default value = 0.012); t CO₂-e (t C)⁻¹
- \( GWP_{N2O} \) = Global Warming Potential for N₂O (= 310 for the first commitment period); t CO₂-e (t N₂O)⁻¹
- \( GWP_{CH}_4 \) = Global Warming Potential for CH₄ (= 21 for the first commitment period); t CO₂-e (t CH₄)⁻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.

### 8.1.2.1 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:

\[
MC_{B,AG,it} = MC_{B,AG \_tree,it} + MC_{B,AG \_nontree,it}
\]

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 (Eq. 33, 34, or 39)
- \( MC_{B,AG \_nontree,it} \) = Mean aboveground biomass carbon stock in non-tree biomass in stratum \( i \) at time \( t \); t C ha⁻¹ (Eq. 18)

Estimation of mean carbon stocks in aboveground non-tree biomass (\( MC_{B,AG \_nontree} \))
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\(^{18}\). 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:

\[
MC_{B,AG\_nontree\_it} = MC_{AG\_nontree\_sample\_it} + MC_{AG\_nontree\_allometric\_it}
\]

where:

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

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

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

**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:

\[
MC_{AG\_nontree\_sample\_it} = 10 * \frac{1}{A_{SFP\_it}} * \sum_{sf=1}^{SFP} MC_{AG\_nontree\_sample\_sf\_it} * CF_{non-tree}
\]

\[
A_{SFP\_it} = \sum_{sfp=1}^{SFP} \sum_{SF=1}^{A_{sampleframe}}
\]

where:

\(^{18}\) 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.
\( MC_{AG\_nontree\_sample} \) = 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.

\( CF_{non-tree} \) Carbon fraction of dominant non-tree vegetation species; dimensionless

\( A_{SFP, i} \) Total area of all non-tree sampling plots in stratum \( i \); m\(^2\)

\( sfp \) \( 1, 2, 3 \ldots \) SFP, sample plots in stratum \( i \)

\( i \) \( 1, 2, 3 \ldots \) \( M \) strata

\( t \) \( 1, 2, 3 \ldots \) \( t \) years elapsed since the start of the project activity

\( sf \) \( 1, 2, 3 \ldots \) \( t \) up to 4 sampling frames per sample plot

10 conversion factor between kg d.m. m\(^{-2}\) and t d.m. ha\(^{-1}\)

**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:

\[
MC_{AG\_nontree\_allometric, i, r, t} = \sum_{l=1}^{N_{l,i}} f_q(vegetation\_parameters) \times CF_q
\] (21)

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\(^{-1}\)

\( i \) \( 1, 2, 3 \ldots \) \( m \) strata

\( r \) \( 1, 2, 3 \ldots \) \( R \) non-tree allometric method sample plots in stratum \( i \)

\( q \) \( 1, 2, 3 \ldots \) \( Q \) non-tree species

\( l \) \( 1, 2, 3 \ldots \) \( N_{l,i,sfp,i} \) sequence number of individual trees in sample plot \( r \) in stratum \( i \) at time \( t \)

\( t \) \( 0, 1, 2, 3 \ldots \) \( t \) 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:

\[
MC_{AG\_nontree\_allometric, it} = \frac{1}{A_{r_i}} \sum_{r=1}^{R} MC_{AG\_nontree\_allometric, r, t}
\] (22)

where:
Mean aboveground biomass carbon stock in stratum \( i \) at time \( t \) from allometric equation method; \( t \) C ha\(^{-1}\)

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

Total area of all non-tree allometric method sample plots in stratum \( i \); ha

\( i \), \( r \), \( t \) \( i \), \( r \), \( t \) \( i \), \( r \), \( t \)

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 5 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)\(^{19}\) and Slaymaker (2003)\(^{20}\).

**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:

\[
A_{\text{crown}} = \frac{A_{\text{ellipse1}} + A_{\text{ellipse2}}}{2}
\]  

(23)

and:

\[
A_{\text{ellipse1}} = \pi \times \left( \frac{(\cos(\text{angle}_{SE}) \times \text{dist}_{SE}) + (\cos(\text{angle}_{SW}) \times \text{dist}_{SW})}{2} \right) \times \left( \frac{\text{dbh} \times 100}{100} \right)
\]

(24)

\[
A_{\text{ellipse2}} = \pi \times \left( \frac{(\cos(\text{angle}_{NW}) \times \text{dist}_{NW}) + (\cos(\text{angle}_{NE}) \times \text{dist}_{NE})}{2} \right) \times \left( \frac{\text{dbh} \times 100}{100} \right)
\]

(25)

where:

\( A_{\text{crown}} \) = area of tree crown, m\(^2\)

\( A_{\text{ellipse}} \) = area of tree crown calculated using north, south, east and west-facing measurements;

\( \text{dbh} \) = diameter at breast height, m


$A_{ellipse2} = \text{area of tree crown calculated using northeast, southeast, northwest and southwest-facing measurements; m}^2$

$angle_N = \text{angle formed between observer’s eye and end of farthest observable canopy branch facing north; degrees}$

$angle_S = \text{angle formed between observer’s eye and end of farthest observable canopy branch facing south; degrees}$

$angle_E = \text{angle formed between observer’s eye and end of farthest observable canopy branch facing east; degrees}$

$angle_W = \text{angle formed between observer’s eye and end of farthest observable canopy branch facing west; degrees}$

$angle_{NE} = \text{angle formed between observer’s eye and end of farthest observable canopy branch facing northeast; degrees}$

$angle_{SE} = \text{angle formed between observer’s eye and end of farthest observable canopy branch facing southeast; degrees}$

$angle_{NW} = \text{angle formed between observer’s eye and end of farthest observable canopy branch facing northwest; degrees}$

$angle_{SW} = \text{angle formed between observer’s eye and end of farthest observable canopy branch facing southwest; degrees}$

$dist_N = \text{distance from observer to end of first canopy branch facing north; meters}$

$dist_S = \text{distance from observer to end of first canopy branch facing south; meters}$

$dist_E = \text{distance from observer to end of first canopy branch facing east; meters}$

$dist_W = \text{distance from observer to end of first canopy branch facing west; meters}$

$dist_{NE} = \text{distance from observer to end of first canopy branch facing northeast; meters}$

$dist_{SE} = \text{distance from observer to end of first canopy branch facing southeast; meters}$

$dist_{NW} = \text{distance from observer to end of first canopy branch facing northwest; meters}$

$dist_{SW} = \text{distance from observer to end of first canopy branch facing southwest; meters}$

$dbh = \text{diameter at breast height of tree; cm}$

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:

$$H_{tree} = \frac{[dist_1 \times \tan(angle_1)] + H_{eye} + [dist_2 \times \tan(angle_2)] + H_{eye}}{2} \quad (26)$$

where:

$H_{tree} = \text{total height of tree, m}$

$dist_1 = \text{horizontal distance from observer to trunk of tree from first vantage point; m}$

$dist_2 = \text{horizontal distance from observer to trunk of tree from second vantage point; m}$

$angle_1 = \text{angle from ground to top of tree measured from first vantage point; degrees}$

$angle_2 = \text{angle from ground to top of tree measured from second vantage point; degrees}$

$H_{eye} = \text{height from ground to observer’s eye; m}$
**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:

\[ TB_{B,AG \_tree,tr} = f(H_{tree}) \]  \hspace{1cm} (27)

\[ TB_{B,AG \_tree,tr} = f(A_{crown}) \]  \hspace{1cm} (28)

\[ TB_{B,AG \_tree,tr} = f(A_{crown} \cdot H_{tree}) \]  \hspace{1cm} (29)

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 Photogrammetry 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. 8.2.1. 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 (m²) 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)

\[
TC_{B,AG_{-tree, tr}} = TB_{B,AG_{-tree, tr}} \cdot CF
\]

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.

\[
PC_{B,AG_{-tree, it}} = \left( \frac{\sum_{tr=1}^{TR} TC_{B,AG_{-tree, tr}} \cdot XF}{1000} \right)
\]

\[
XF = \frac{10,000}{AP}
\]

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\(^{-1}\)
\[ TC_{B,AG,tree,it} = \text{Carbon stock in above-ground biomass per tree } tr \text{ under the baseline scenario; kg C tree}^{-1} \]

\[ XF = \text{Plot expansion factor from per plot values to per hectare values} \]

\[ AP = \text{Plot area; m}^2 \]

\[ tr = 1, 2, 3, \ldots, TR \text{ trees (TR = total number of trees in the plot)} \]

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

\[
MC_{B,AG,tree,it} = \frac{\sum_{pl} PC_{B,AG,tree,it}}{PL_{it}} \tag{33}
\]

where:

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

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

\[ pl = \text{Plot number in stratum } i; \text{ dimensionless} \]

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

**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\(^{21}\):

\[
MC_{B,AG\_tree,it} = MV_{B,AG\_tree,it} \cdot \phi_i \cdot BEF \cdot CF
\]

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\(^{-1}\)
- \(\phi_i\) = 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.

**Allometric Method**

**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.

\[
TB_{B,AG\_tree,tr} = f(DBH, H_{tree})
\]

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 \(\pm 10\%\) 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 permit, the carbon content can be determined in the laboratory. Finally, allometric equations are

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\(^{21}\) IPCC GPG-LULUCF Equation 4.3.1
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

\[ TC_{B, AG \_tree, tr} = TB_{B, AG \_tree, tr} \cdot CF \]  

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.

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

\[ XF = \frac{10,000}{AP} \]

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:

\[ MC_{B, AG \_tree, it} = \frac{\sum_{pl=1}^{PL} PC_{B, AG \_tree, it}}{PL_{it}} \]  

where:

- \( MC_{B, AG \_tree, it} \) = Mean carbon stock within each stratum; t C ha\(^{-1}\)
- \( PC_{B, AG \_tree, it} \) = Plot level carbon stock in above ground biomass under the baseline scenario in stratum \( i \), time \( t \); t C ha\(^{-1}\)
- \( PL_{it} \) = Number of plots in stratum \( i \), time \( t \); ha.
where:

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

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

\[ pl = \text{Plot number in stratum } i, \text{ time } t; \text{ dimensionless} \]

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

8.1.3 Estimation of \( R_{B,\text{growthit}} \) (increase in carbon stocks due to aboveground biomass growth of vegetation in baseline land-use)

In the baseline scenario, a new land use 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 land use. This biomass growth is estimated as:

\[ R_{B,\text{growthit}} = R_{ARB,it} \cdot \frac{A_{planted}^{44}}{12} \]  \hspace{1cm} (40)

where:

\[ R_{B,\text{growthit}} = \text{total annual increase in carbon stock due to growth of living trees} \]

\[ R_{ARB,it} = \text{average annual increase in carbon stock due to growth of living trees} \]

\[ A_{planted}^{44} = \text{area of biomass growth on future land use in the baseline scenario in stratum } i \]

\[ \frac{44}{12} = \text{ratio of molecular weights of CO}_2 \text{ and carbon; dimensionless} \]

\( R_{ARB,it} \) 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 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 sites at a minimum. To fulfill 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. 8.1.2.1 for measurement of trees. Refer to Section 5 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:

**Linear function:** 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:

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

and:

$$R_{ARB,it} = slp$$

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$^{-1}$

**Non-linear function:** 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:

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

and:

$$MC_{FLU,AC,it} = MaxYld \cdot (1 - \exp(-prm_1 \cdot age))^{prm_2}$$

$$prm_1 = -\frac{\ln[1 - (0.8)^{age_{peak}}]}{age_{peak}}$$

$$prm_2 = \frac{1}{1 - prm_3}$$

where:
\( MC_{\text{FLU,AC},it} \) = mean carbon stock in above-ground biomass on the future land use under the baseline scenario, stratum \( i \), time \( t \); t C ha\(^{-1}\).

\( MC_{\text{FLU,AC},it-1} \) = mean carbon stock in above-ground biomass on the future land use under the baseline scenario, stratum \( i \), time \( t-1 \); t C ha\(^{-1}\).

\( R_{\text{ARB,}it} \) = average annual increase in carbon stock due to biomass growth of living trees on the future land use under the baseline scenario, stratum \( i \), time \( t \); t C ha\(^{-1}\) yr\(^{-1}\).

\( \text{age} \) = age of stand; years

\( \text{MaxYld} \) = Maximum peak carbon yield; t C ha\(^{-1}\)

\( \text{prm1} \) = intermediate calculation using fitted parameter \( Prm2 \) when estimating biomass accumulation using non-linear function; dimensionless

\( \text{prm2} \) = fitted parameter where \( \text{prm3} \) varies between 0 and 1 when fitting biomass accumulation values to a non-linear function; dimensionless

\( \text{age}_{\text{peak}} \) = age of stand at peak production; years

### 8.1.4 Estimation of \( E_{\text{harvest,}it} \) (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:

\[
E_{\text{harvest,}it} = \left( \frac{44}{12} \cdot \left( C_{\text{extracted},BH,it} - C_{\text{woodprod},BH,it} \right) \right) + E_{\text{BH, BiomassBurn,}it} \quad (47)
\]

where:

\( E_{\text{harvest,}it} \) = emissions from harvesting operations in stratum \( i \) at time \( t \); t CO\(_2\)-e

\( C_{\text{extracted},BH,it} \) = Carbon stocks of timber extracted at harvest \( H \) under the baseline scenario in stratum \( i \) at time \( t \); t C (Eq. 50)

\( C_{\text{woodprod},BH,it} \) = carbon stocks from harvest \( H \) moving into long term wood products under the baseline scenario for stratum \( i \) at time \( t \); t C (Eq. 51)

\( E_{\text{BH, BiomassBurn,}it} \) = 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 (Eq. 54)

\( \frac{44}{12} \) = ratio of molecular weights of CO\(_2\) and carbon; dimensionless

And:

\[
C_{\text{extracted},BH,it} = MC_{\text{FLU,AC},it} \cdot PBH \cdot A_{\text{clear},BH,it} \quad (48)
\]

\[
C_{\text{woodprod},BH,it} = C_{\text{extracted},BH,it} \cdot p \quad (49)
\]
Where:

\[ C_{\text{extracted},BH,ij} = \text{Carbon stocks from trees extracted at harvest } H \text{ under the baseline scenario in stratum } i \text{ at time } t; \text{ t C} \]

\[ C_{\text{woodprod},BH,ij} = \text{carbon stocks from harvest } H \text{ moving into long term wood products under the baseline scenario for stratum } i \text{ at time } t; \text{ t C} \]

\[ MC_{\text{FLU,AC},ij} = \text{mean carbon stock in above-ground biomass on the future land use under the baseline scenario in stratum } i, \text{ time } t; \text{ t C ha}^{-1} \text{ (Eq. 44)} \]

\[ PBH = \text{average proportion of aboveground carbon stock removed during harvest } H \text{ under the baseline scenario for stratum } i, \text{ time } t; \text{ dimensionless (Eq. 50)} \]

\[ A_{\text{cleared},BH,ij} = \text{Area cleared at harvest } H \text{ under the baseline scenario for stratum } i, \text{ in time } t; \text{ ha} \]

\[ p = \text{percent of harvest industrial roundwood going into long term wood products; dimensionless} \]

The average proportion of aboveground carbon stock removed during harvest \( H \) \( (PBH) \) can be estimated by dividing the carbon removed during harvest operations by mean biomass carbon stocks in the year of harvest (estimated in Eq. 45 above):

\[ PBH = \frac{MC_{\text{BH,timber},ij}}{MC_{\text{FLU,AC},ij}} \]  \hspace{1cm} (50)

where:

\[ MC_{\text{BH,timber},ij} = \text{mean carbon stock in timber removed during harvest } H \text{ under the baseline scenario for stratum } i, \text{ time } t; \text{ t C ha}^{-1} \text{ (Eq. 51)} \]

\[ MC_{\text{FLU,AC},ij} = \text{mean carbon stock in above-ground biomass on the future land use under the baseline scenario, stratum } i, \text{ time } t; \text{ t C ha}^{-1} \text{ (Eq. 44)} \]

The carbon removed during harvest \( H \) \( (MC_{\text{BH,timber},ij}) \) can be estimated from volume data (these data are typically collected by timber management companies) as follows:

\[ MC_{\text{BH,timber},ij} = MV_{\text{BH,timber},ij} \cdot \phi_i \cdot CF \]  \hspace{1cm} (51)

where:

\[ MC_{\text{BH,timber},ij} = \text{mean carbon stock in timber removed during harvest } H \text{ under the baseline scenario for stratum } i, \text{ time } t; \text{ t C ha}^{-1} \]

\[ MV_{\text{BH,timber},ij} = \text{Mean merchantable volume under the baseline scenario in stratum } i \text{ at time } t; \text{ m}^3 \text{ ha}^{-1} \]

\[ \phi_i = \text{specific wood density of harvested wood, for stratum } i; \text{ t d.m. m}^3 \]

\[ CF = \text{carbon fraction; t C (tonne d.m.)}^{-1}; \text{ IPCC default value } = 0.5 \]
Emissions from aboveground biomass burning during harvesting operations ($E_{BH, BiomassBurn,it}$) are estimated based on revised IPCC 1996 Guidelines for LULUCF:

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

(52)

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:

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

(53)

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$^{-1}$ (Eq. 44)
- $PBH$ = average proportion of aboveground carbon stock removed during harvest $H$ under the baseline scenario for stratum $i$, time $t$; (Eq. 50)
- $A_{cleared}^{BH,it}$ = 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 ($1-PBH$) 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 2.6 of the 2006 IPCC AFOLU Guidelines, which include values for a wider range of vegetation types than values in Table 3.A.14 of IPCC GPG-LULUCF and also give values for both mean and standard deviation. If no appropriate combustion efficiency can be used, the IPCC default of 0.5 should be used.
Emissions of non-CO\textsubscript{2} gases are given by:\textsuperscript{22}

\[
E_{BH, BiomassBurn,N2O,t} = E_{BH, BiomassBurn,CO2,t} \cdot \frac{12}{44} \cdot \left( \frac{N}{\text{Cratio}} \right) \cdot ER_{N2O} \cdot \frac{44}{28} \cdot GWP_{N2O} \tag{54}
\]

\[
E_{BH, BiomassBurn,CH4,t} = E_{BH, BiomassBurn,CO2,t} \cdot \frac{12}{44} \cdot ER_{CH4} \cdot \frac{16}{12} \cdot GWP_{CH4} \tag{55}
\]

where:

- \(E_{BH, BiomassBurn,CO2,t}\) = CO\textsubscript{2} emission from aboveground biomass burning at harvest H under the baseline scenario in stratum \(i\), time \(t\); t CO\textsubscript{2}-e.
- \(E_{BH, BiomassBurn,N2O,t}\) = N\textsubscript{2}O emission from aboveground biomass burning at harvest H under the baseline scenario in stratum \(i\), time \(t\); t CO\textsubscript{2}-e.
- \(E_{BH, BiomassBurn,CH4,t}\) = CH\textsubscript{4} emission from aboveground biomass burning at harvest H under the baseline scenario in stratum \(i\), time \(t\); t CO\textsubscript{2}-e.
- \(N / \text{Cratio}\) = nitrogen-carbon ratio (IPCC default = 0.01); dimensionless
- \(ER_{N2O}\) = emission ratio for N\textsubscript{2}O (IPCC default value = 0.007); t CO\textsubscript{2}-e./t C
- \(ER_{CH4}\) = emission ratio for CH\textsubscript{4} (IPCC default value = 0.012); t CO\textsubscript{2}-e./t C
- \(GWP_{N2O}\) = Global Warming Potential for N\textsubscript{2}O (= 310 for the first commitment period); t CO\textsubscript{2}-e./t N\textsubscript{2}O
- \(GWP_{CH4}\) = Global Warming Potential for CH\textsubscript{4} (= 21 for the first commitment period); t CO\textsubscript{2}-e./t CH\textsubscript{4}

**8.2 Estimation of \(E_{B,p,t}\) (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:

\[
E_{B,p,t} = E_{B,Drainage,t} + E_{B,PeatBurn,t} \tag{56}
\]

where:

- \(E_{B,p,t}\) = total baseline GHG emissions from peat under the baseline scenario in stratum \(i\) at time \(t\); t CO\textsubscript{2}-e.
- \(E_{B,Drainage,t}\) = GHG emissions from peat drainage under the baseline scenario in stratum \(i\) at time \(t\); t CO\textsubscript{2}-e. (Eq. 57)
- \(E_{B,PeatBurn,t}\) = GHG emissions from peat burning under the baseline scenario in stratum \(i\), time \(t\); t CO\textsubscript{2}-e. (Eq. 60)

**8.2.1 Estimation of \(E_{B,Drainage,t}\) (GHG emissions from peat drainage)**

\textsuperscript{22} Refers to Table 5.7 in 1996 Revised IPCC Guideline for LULUCF and Equation 3.2.19 in IPCC GPG-LULUCF
GHG emissions from peat drainage resulting from land clearing activities for a baseline land-use activity are estimated as:

\[ E_{B,\text{drain},it} = A_{B,\text{drain},it} \cdot ME_{B,dd, it} \]  

(57)

and:

\[ ME_{B,dd, it} = f(D_{B,\text{drain},it}) \]  

(58)

where:

- \( E_{B,\text{drain}, it} \) = \( CO_2 \) emissions from peat drainage under the baseline scenario in stratum \( i \) at time \( t \), t \( CO_2 \)-e
- \( A_{B,\text{drain},it} \) = 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\(^{-1}\)
- \( D_{B,\text{drain},it} \) = average depth of peat drainage or average depth to water table under the baseline scenario in stratum \( i \), time \( t \); cm

### 8.2.1.1 Depth of peat drainage \( (D_{B,\text{drain},it}) \)

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)\(^ {23} \) 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).**

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Minimum</th>
<th>Likely</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large croplands, including plantations</td>
<td>0.80</td>
<td>0.95</td>
<td>1.10</td>
</tr>
<tr>
<td>Small-scale agriculture</td>
<td>0.40</td>
<td>0.60</td>
<td>0.80</td>
</tr>
</tbody>
</table>

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. Because fire is assumed in the

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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 net drainage depth of 46 cm.

### 8.2.1.2 Time dimension of peat drainage

Equation 58 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$^{24}$. 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 $t^\wedge$, where $t^\wedge$ 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:

$$t^\wedge = \frac{D_{\text{peat}} \cdot 100}{4.5}$$

(59)

where:

- $t^\wedge$ = number of years of peat emissions due to continued drainage; years
- $D_{\text{peat}}$ = 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 61 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.

### 8.2.1.3 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 $A_{\text{cleared}}^{\text{cleared}}$. 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 $A_{B,\text{it}}^{\text{cleared}}$ for a 2,500 ha planned plantation in the baseline is 500 ha for the first five years, then the area impacted by drainage ($A_{B,\text{drain,\text{it}}}$) in Eq. 59 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 $t^\text{e}$ is reached.

8.2.1.4 Relationship between CO$_2$ emissions and drainage depth (Eq. 58)

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$^{25,26}$ where $ME_{B,\text{dd,\text{it}}} = 0.91 \times D_{B,\text{drain,\text{it}}}$ (or $ME_{B,\text{dd,\text{it}}} = 9 \text{ t CO}_2 \text{ha}^{-1} \text{yr}^{-1}$ 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 Applicability Condition F in Section 3. Improvements to this regression model should be made as new data emerge.

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$^{27}$ 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.

8.2.2 Estimation of $E_{B,\text{PeatBurn,\text{it}}}$ (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 follow:

$$E_{B,\text{PeatBurn,\text{it}}}=E_{B,\text{PeatBurn,CO}_2,\text{it}}+E_{B,\text{PeatBurn,CH}_4,\text{it}}$$

and:

$$E_{B,\text{PeatBurn,CO}_2,\text{it}} = \frac{M_{B,p,\text{it}} \times EF_{\text{CO}_2}}{10^6}$$


\[ E_{B,\text{PeatBurn},CH_4,rt} = \frac{M_{B,p,rt} \times EF_{CH_4} \times GWP_{CH_4}}{10^6} \]  

\[ M_{B,p,rt} = D_{B,\text{burn},rt} \times A_{B,\text{burn},rt} \times 10000 \times BD_i \]  

where:

- \( E_{B,\text{PeatBurn},it} \) = Total increase in CO\(_2\)-e emissions as a result of peat burning under the baseline scenario in stratum \( i \), time \( t \); t CO\(_2\)e
- \( E_{B,\text{PeatBurn},CO_2,rt} \) = total CO\(_2\) emissions from peat burning under the baseline scenario in stratum \( i \), time \( t \); t CO\(_2\)e
- \( E_{B,\text{PeatBurn},CH_4,rt} \) = total CH\(_4\) emissions from peat burning under the baseline scenario in stratum \( i \), time \( t \); t CO\(_2\)e
- \( M_{B,p,rt} \) = mass of peat burned under the baseline scenario in stratum \( i \), time \( t \); tons
- \( EF_{CO_2} \) = CO\(_2\) emissions from the combustion of peat, g CO\(_2\) (t peat)\(^{-1}\)
- \( EF_{CH_4} \) = CH\(_4\) emissions from the combustion of peat, g CH\(_4\) (t peat)\(^{-1}\)
- \( GWP_{CH_4} \) = Global Warming Potential for CH\(_4\) (IPCC default = 21 for the first commitment period); t CO\(_2\)-e, (t CH\(_4\))\(^{-1}\)
- \( D_{B,\text{burn},rt} \) = depth of peat burned under the baseline scenario in stratum \( i \) at time \( t \); meters
- \( A_{B,\text{burn},rt} \) = 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

### 8.2.2.1 Estimation of peat depth burned (\(D_{B,\text{burn},rt}\))

Single fire events in human-induced fires in southeast Asian peatlands have resulted in losses up to well over one meter of peat\(^{28,29,30}\). 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 8.2.1.1 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 \textit{ex ante} for all strata using the most up-to-date information as reported in the literature. At present, Couwenberg et al. (2009)\(^{31}\) 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 19.3.2 of the monitoring methodology below.)

8.2.2.2 Estimation of area of peat burned under the baseline scenario \( (A_{\text{burn, it}}) \)

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 \( A_{\text{burn, it}} \) shall be equal to the annual rate of clearing \( A_{\text{cleared}}^{\text{it}} \).

8.2.2.3 Estimation of peat bulk density \( (BD_i) \)

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 5 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 \( \leq 34 \) 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)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Bulk Density (g cm(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Page et al. 2002(^{32})</td>
<td>0.100</td>
</tr>
</tbody>
</table>


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

8.2.2.4 Estimation of CO₂ and CH₄ emission factors (EF<sub>CO₂</sub>, EF<sub>CH₄</sub>)

Muraleedharan et al. (2000) measured direct emissions from the combustion of tropical peat at two temperatures (smouldering stage: 480 °C and flaming stage: 600 °C). The most abundant C-containing combustion product was CO₂, followed by CO and CH₄. Emission factors for CO₂ and CH₄ 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 (CO₂ + CH₄ reported as CO₂ equivalents) and thus a conservative baseline scenario.

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

<table>
<thead>
<tr>
<th>Component</th>
<th>Temperature (°C)</th>
<th>480</th>
<th>600</th>
<th>g (ton peat)⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>185,000</td>
<td>149,591</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


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

Figure 2 below shows how baseline equations are related and indicates in yellow the equations that include at least one parameter for which uncertainty estimation is required.

Figure 2. Conceptual diagram of baseline equations. Equation numbers are shown in parentheses. Yellow boxes indicate equations that include one or more parameters for which uncertainty shall be estimated. In the bottom right of the figure, all parameters for which uncertainty must be estimated (or conservative values used) are organized by source.

9. **Ex Ante Actual Net Avoided GHG Emissions**
The *ex ante* actual net avoided GHG emissions represent the sum of the baseline GHG emissions within the project boundary, minus the increase in greenhouse gas emissions by sources measured in CO₂ equivalents within the project boundary that are a result of the implementation of a project activity.

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 methodology. The actual net GHG emissions avoided represent the sum of the baseline GHG emissions within the project boundary.

\[
C_{ACTUAL} = C_{BSL}
\]

where:

- \(C_{ACTUAL}\) = actual net greenhouse gas emissions avoided; t CO₂-e
- \(C_{BSL}\) = sum of the baseline GHG emissions (aboveground and peat); t CO₂-e

Note: In this methodology Eq. 64 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.

10. Leakage

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 CO₂-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. When REDD project activities result in reductions in wood harvest, it is likely that production could shift to other areas of the country to compensate for the reduction, and thus leakage as a result of market effects must also be considered in this scenario.

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.

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

\[
LK = LK_{MarketEffects} + LK_{ActivityDisplacement}
\]

where:

- \(LK\) = Leakage emissions resulting from displacement of economic activities and market effects; t CO₂-e
- \(LK_{MarketEffects}\) = Total GHG emissions due to market effects leakage through decreased timber harvest; t CO₂-e (Eq. 66)
- \(LK_{ActivityDisplacement}\) = Total GHG emissions due to activity shifting leakage for projects preventing planned deforestation; t CO₂-e (Eq. 68)
10.1 Market Leakage

When REDD project activities result in reductions in wood harvest, it is likely that production could shift to other areas of the country to compensate for the reduction. Therefore, in cases where the project area would be harvested for commercial timber before clearing the site for a new land use, market effects leakage must be estimated as the baseline emissions from logging multiplied by a leakage factor:

\[
LK_{MarketEffects} = \sum_{i=1}^{n} \sum_{t=1}^{m} LK_{ME, it}
\]

\[
LK_{ME, it} = LF_{ME, i} \times C_{B,XBT, it}
\]

Where:

- \( LK_{MarketEffects} \) = Total GHG emissions due to market effects leakage through decreased harvest; t CO\(_2\)-e
- \( LK_{ME, it} \) = Total GHG emissions due to market effects leakage through decreased harvest in stratum \( i \) at time \( t \); t CO\(_2\)-e
- \( LF_{ME, i} \) = Leakage factor for market effects calculations; dimensionless
- \( C_{B,XBT, it} \) = Carbon emission due to displaced timber harvests in the baseline scenario in stratum \( i \) at time \( t \); t CO\(_2\)-e

The amount of leakage is determined by where harvesting would likely be displaced to. If in the forests to which displacement would occur a lower proportion of biomass in commercial species is in merchantable material than in the project area, then more trees will need to be cut to supply the same volume and thus higher emissions should be expected. In contrast, if a higher proportion of biomass of commercial species is merchantable in the displacement forest than in the project forest, then a smaller area would need to be harvested and lower emissions would result.

Each project thus shall calculate within each stratum the proportion of total biomass in commercial species that is merchantable \((PMP_i)\). Merchantable biomass per stratum is conservatively defined as the total volume (converted to biomass) of all commercially valuable trees within a stratum that are above the minimum size class sold in the local timber market (see Applicability Condition J). \( PMP_i \) is therefore equal to the merchantable biomass as a proportion of total aboveground tree biomass for stratum \( i \) within the project boundaries. \( PMP_i \) shall then be compared to the mean proportion of total biomass that is merchantable for each forest type \((PML_{FT})\) to which displacement is likely to occur.

The following deduction factors \((LF_{ME, i})\) shall be used:

- \( PML_{FT} \) is equal (±0.15) to \( PMP_i \): \( LF_{ME, i} = 0.4 \)
- \( PML_{FT} \) is > 0.15 less than \( PMP_i \): \( LF_{ME, i} = 0.7 \)
- \( PML_{FT} \) is >0.15 greater than \( PMP_i \): \( LF_{ME, i} = 0.2 \)

Where:

- \( PML_{FT} \) = Mean merchantable biomass as a proportion of total aboveground tree biomass for each forest type; dimensionless
- \( PMP_i \) = Merchantable biomass as a proportion of total aboveground tree biomass for stratum \( i \) within the project boundaries; dimensionless
- \( LF_{ME, i} \) = Leakage factor for stratum \( i \) market-effects calculations; dimensionless
Instead of applying the default market leakage discounts, project proponents may opt to estimate the project’s market leakage effects across the entire country and/or use analysis(es) from other similar projects to justify a different market leakage value. A description of the market leakage assessment, including steps for determining where leakage is likely to occur (i.e., to which forest types leakage is likely to occur) and what the carbon stocks of those lands are, shall be outlined in the PDD. The outcome of this assessment conducted at first VCU issuance (whether using default discounts or project specific analysis(es)) shall be subject to the VCS double approval process. 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.

The next step is to estimate the emissions associated with the displaced logging activity – this is based on the total volume that would have been logged in the project area in the baseline scenario. The emission due to the displaced logging has two components: the biomass carbon of the extracted timber and the biomass carbon in the forest damaged in the process of timber extraction:

\[
C_{B,XBT,i,t} = \left( V_{B,i,t} \times \phi_i \times CF \right) + \left( V_{B,i,t} \times LDF \right) \times \frac{44}{12}
\]

Where:
- \(C_{B,XBT,i,t}\) = Carbon emission due to displaced timber harvests in the baseline scenario in stratum \(i\) at time \(t\); t CO₂-e
- \(V_{B,i,t}\) = Volume to be extracted under the baseline scenario in stratum \(i\) at time \(t\); m³
- \(\phi_i\) = volume-weighted average wood density; t d.m. m⁻³ merchantable volume
- \(CF\) = carbon fraction of dry matter (0.5 t C / t biomass); dimensionless
- \(LDF\) = Logging damage factor; t C m⁻³ (default 0.37 t C m⁻³)
- \(i\) = 1, 2, 3, ..., \(m_{BL}\) baseline strata
- \(t\) = 1, 2, 3, ..., \(t^*\) years elapsed since the projected start of the REDD project activity

The total volume to be extracted under the baseline scenario in stratum \(i\) at time \(t\) (\(V_{B,i,t}\)) can be estimated by multiplying the plot-level volume per stratum (\(MV_{B,i}\), see Eq. 34) by the area cleared or logged in stratum \(i\) at time \(t\) (\(A_{B,i,t}^{cleared}\) or \(A_{B,i,t}^{logged}\) if different from \(A_{B,i,t}^{cleared}\)).

The logging damage factor (\(LDF\)) is a representation of the quantity of emissions that will ultimately arise per unit of extracted timber (m³). These emissions arise from the non-commercial portion of the felled tree (the branches and stump) and trees incidentally killed during tree felling. The default value given here comes from the slope of the regression equation between carbon damaged and volume extracted based on 534 logging gaps measured by Winrock International in Bolivia, Belize, Mexico, the Republic of Congo, Brazil, and Indonesia:
Methods used by Winrock are described in Pearson et al. (2010)\textsuperscript{36} and in reports to US Agency for International Development\textsuperscript{37}.

\subsection*{10.2 Activity Displacement Leakage}

Leakage due to activity displacement represents the increase in GHG emissions by sources which occur outside the project boundary that are measurable and attributable to the project activity. 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. Under Applicability Condition H in Section 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. No increases in GHG emissions caused by displacement of activities associated with the project are expected and \( LK = 0 \) if it can be demonstrated that 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. 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, clearing intact forests for plantation establishment); if they have changed, the project shall quantify the impact of

\begin{center}
\texttt{y = 0.3663x}
\texttt{R\textsuperscript{2} = 0.70}
\end{center}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure.png}
\caption{Dead Wood Created (t C) vs. Volume (m3)}
\end{figure}

\textsuperscript{36} Pearson, TRH and Brown, S. 2010. Impact of selective logging on the carbon stocks of tropical forests: case studies from Belize, Bolivia, Brazil, Indonesia, Mexico and the Republic of Congo.

\textsuperscript{37} Deliverables 9, 10, 13a, 17, 21, and 24 under Carbon and Co-Benefits from Sustainable Land-Use Management project: Cooperative Agreement No. EEM-A-00-03-00006-00.
these management changes and deduct the associated reductions in carbon stocks or increases in GHG emissions from $C_{BL}$. 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. The area of activity shifting leakage shall be assessed for five full years beyond the date at which deforestation was projected to occur in the baseline. However, emissions resulting from activity shifting leakage shall be tracked beyond the initial year of clearing where applicable to account for emissions from peat and mineral soils that continue after the initial year of clearing. Additional guidance for calculation of emissions is given in Section 10.2.2 below.

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.

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

\[
L_K^{\text{Activity Displacement}} = \sum_{t=1}^{t*} \sum_{m=1}^{m_{LK}} L_K^{AD,it} \quad (69)
\]

where:

- $L_K^{\text{Activity Displacement}}$ = Total GHG emissions due to activity shifting leakage for projects preventing planned deforestation; t CO$_2$-e (Eq. 71)
- $L_K^{AD,it}$ = Total GHG emissions due to activity shifting leakage in stratum $i$ at time $t$ for projects preventing planned deforestation; t CO$_2$-e
- $i$ = 1, 2, 3, … $m_{LK}$ leakage strata
- $t$ = 1, 2, 3, … $t^*$ years elapsed since the start of the project activity

In each stratum, GHG emissions due to activity shifting leakage at time $t$ consist of two components: (1) the initial changes in carbon stocks and GHG emissions that are accounted for in the year of clearing; and (2) continued changes in carbon stocks and GHG emissions that occur in subsequent years as a result of peat drainage or clearing land on mineral soils for annual cropland:

\[
L_K^{AD,it} = (L_K^{\text{plannedit}} \times \Delta C_{it,\text{init}}) + \sum_{i=1}^{t-1} (L_K^{\text{plannedit}} \times \Delta C_{it,\text{continued}}) \quad (70)
\]

Where:

- $L_K^{AD,it}$ = Total GHG emissions due to activity shifting leakage in stratum $i$ at time $t$ for projects preventing planned deforestation; t CO$_2$-e
- $L_K^{\text{plannedit}}$ = The area of activity shifting leakage in stratum $i$ at time $t$; ha
- $\Delta C_{it,\text{init}}$ = average initial carbon stock changes and greenhouse gas emissions in stratum $i$ at time $t$ (excluding timber emissions where applicable); t CO$_2$-e ha$^{-1}$.
- $\Delta C_{it,\text{continued}}$ = average carbon stock changes and greenhouse gas emissions in stratum $i$ at...
time \( t \) as a result of continued emissions; \( t \text{CO}_2\text{-e ha}^{-1} \)

The second term of the equation (continued emissions) shall be included only in years after the initial year of clearing.

10.2.1 Area of activity shifting leakage \( (LKA_{\text{planned},t}) \)

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 5 above.

The overall approach for calculating the area of activity shifting leakage is to first calculate the total area over which deforestation is forecast to occur across all of the land managed by the baseline agent of deforestation in year \( t \), including the baseline projected deforestation within the project boundaries. Second, the area of deforestation predicted to occur within the project boundary in year \( t \) is subtracted from the total area deforested in year \( t \) across all of the land managed by the baseline agent of deforestation, which yields the expected area of deforestation in year \( t \) by the focal agent if no leakage had occurred. Third, the difference between the expected area of deforestation in year \( t \) 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 area of forest clearance in year \( t \) for the deforestation agent**

Two options exist for estimating the baseline rate of forest clearance by the deforestation agent. Only if a historic trend analysis (Option 1.1) is not feasible shall Option 1.2 be used.

**Option 1.1 Baseline deforestation rate based on historic deforestation trend**

With this approach, the baseline annual deforestation rate by the baseline deforestation agent can be estimated by extrapolating the historical annual trend using a linear regression. Survey the 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 within each leakage stratum each year over the last 5-10 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 the 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 1.2 (“historical average”) must be used. The linear regression is as follows:

\[
WoPA_i(t) = a + (WoPR_i * t) \quad (71)
\]

Where:

- \( WoPA_i(t) \) = Total (cumulative) area of forest cleared by the baseline agent of planned deforestation in stratum \( i \) at time \( t \); ha
- \( a \) = Estimated intercept of the regression line; ha
- \( WoPR_i \) = Slope of the linear regression, i.e., rate of deforestation by the baseline agent in the absence of the project in stratum \( i \); ha cleared at time \( t \)
The annual area of deforestation by the baseline agent in the absence of the project in stratum $i$ at time $t$ is therefore equal to the slope of the regression line, or $WoPR_{it}$.

**Option 1.2: Baseline deforestation rate based on historic deforestation average**

Under this approach, the baseline annual deforestation rate by the deforestation agent is assumed to be equal to the average cleared area during the past 5-10 years.

To implement this option, survey the deforestation agent and, if available, examine official records to determine the total area deforested by the deforestation agent within each leakage stratum over the previous five to ten years within the country.

$$WoPR_{it} = \frac{HistHa_i}{n_{yrs}}$$

Where:

- $WoPR_{it}$ = Rate of deforestation by the baseline agent in the absence of the project in stratum $i$; ha cleared at time $t$
- $HistHa_i$ = Total number of hectares of forest cleared by the baseline agent of the planned deforestation in the $n$ years prior to project implementation in stratum $i$; ha
- $i = 1, 2, 3, ..., m_{LK}$ strata
- $n_{yrs}$ = number of years included in the analysis of deforestation; dimensionless

Where there is no history of deforestation within a given stratum and no verifiable plans for controlled lands and future-controlled lands by the deforestation agent, then $WoPR_{it}$ should be set to the planned baseline rate for the project.

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

For each stratum $i$ at each time $t$, subtract the area of planned deforestation for within the project area from the historic area of deforestation by the agent of deforestation to calculate the new “zero leakage” area of forest cleared at time $t$.

$$NewR_{it} = WoPR_{it} - A_{B, it}^{cleared}$$

Where:

- $NewR_{it}$ = New calculated area of forest clearance in stratum $i$ and time $t$ by the baseline agent of planned deforestation where no leakage is occurring; ha
- $WoPR_{it}$ = Area of deforestation by the baseline agent of the planned deforestation in stratum $i$ at...
time $t$ in the absence of the project; ha

\[ A_{B_{it}}^{\text{cleared}} = \text{Area cleared under the baseline scenario for stratum } i, \text{ in time } t; \text{ ha} \]

\[ i = 1, 2, 3, \ldots m_{LK} \text{ leakage strata} \]

\[ t = 1, 2, 3, \ldots t^* \text{ years elapsed since the start of the project activity} \]

**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 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. There is no requirement to track international leakage.

\[ LKA_{\text{planned}_it} = A_{\text{def}_{LK,it}} - NewR_{it} \quad (74) \]

Where:

\[ LKA_{\text{planned}_it} = \text{The area of activity shifting leakage at time } t; \text{ ha} \]

\[ NewR_{it} = \text{New calculated area of forest clearance by the baseline agent of the planned deforestation in stratum } i \text{ at time } t \text{ when no leakage is occurring; ha} \]

\[ A_{\text{def}_{LK,it}} = \text{The total observed area of deforestation by the baseline agent in stratum } i \text{ at time } t; \text{ ha} \]

\[ i = 1, 2, 3, \ldots m_{LK} \text{ leakage strata} \]

\[ t = 1, 2, 3, \ldots t^* \text{ years elapsed since the start of the project activity} \]

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

### 10.2.2 Net carbon stock changes and GHG emissions ($\Delta C_{it_{-init}}$ and $\Delta C_{it_{-continued}}$)

*Initial emissions resulting from land use conversion*

$\Delta C_{it_{-init}}$ represents the average initial carbon stock changes and greenhouse gas emissions caused by deforestation activities in a leakage stratum $i$ at time $t$.

The equation for estimating $\Delta C_{it_{-init}}$ depends on the area of activity displacement leakage, $LKA_{\text{planned}_it}$ (Eq. 74), relative to the area deforested in the baseline scenario, $A_{B_{it}}^{\text{cleared}}$. If $LKA_{\text{planned}_it}$ is less than 40% of $A_{B_{it}}^{\text{cleared}}$, then leaked emissions from timber harvesting are excluded from the calculation because they are accounted for in market effects leakage calculations (Section 10.1). The rationale for using this 40% threshold is that the VCS market leakage table assumes a market leakage factor of 0.4 (40%) in cases where the likely source of timber is similar to the project conditions. If
activity shifting leakage leads to timber production less than or equal to this 40% threshold, then emissions have already been covered by market leakage. In cases where $LKA_{\text{planned}}^{\text{cleared}}$ is greater than 40% of $A_{B,i,t}^{\text{cleared}}$, then not all timber emissions will have been covered under market leakage and the additional emissions need to be accounted for in activity displacement leakage.

Both calculations include other emission sources (non-timber biomass cleared for site preparation, emissions from the burning and drainage of peat).

For leakage strata that are also included as baseline strata, $\Delta C_{i,t,\text{init}}$ is calculated as follows:

If $LKA_{\text{planned}}^{\text{cleared}} \leq 40\%$ of $A_{B,i,t}^{\text{cleared}}$:

$$
\Delta C_{i,t,\text{init}} = \left[ \frac{44}{12} \times MC_{B,AG,i,t} - C_{ML,i,t} \right] + \frac{E_{B,p,i,t}}{A_{B,i,t}^{\text{cleared}}} 
$$

(75)

$$
C_{ML,i,t} = (B_{B,i,t}^{\text{logged}} \times CF) + \left( MV_{B,AG\_tree,i,t} \times LDF \right)
$$

(76)

Where:

- $\Delta C_{i,t,\text{init}}$ = average initial carbon stock changes and GHG emissions for stratum $i$ at time $t$; t CO$_2$e ha$^{-1}$
- $C_{ML,i,t}$ = average carbon stocks accounted for as timber emissions under market leakage; t C ha$^{-1}$
- $MC_{B,AG,i,t}$ = mean carbon stock in above-ground living biomass under the baseline scenario for stratum $i$, time $t$; t C ha$^{-1}$ (Eq. 17)
- $B_{B,i,t}^{\text{logged}}$ = timber biomass logged under the baseline scenario for stratum $i$ at time $t$; t d.m. ha$^{-1}$ (Eq. 11)
- $CF$ = carbon fraction of dry matter (0.5 t C / t biomass); dimensionless
- $A_{B,i,t}^{\text{cleared}}$ = Area cleared under the baseline scenario for stratum $i$, in time $t$; ha
- $E_{B,p,i,t}$ = total baseline GHG emissions from peat under the baseline scenario in stratum $i$ at time $t$; t CO$_2$e (Eq. 56)
- $MV_{B,AG\_tree,i,t}$ = mean merchantable volume under the baseline scenario in stratum $i$ at time $t$; m$^3$ ha$^{-1}$
- $LDF$ = Logging damage factor; t C m$^{-3}$ (default 0.37 t C m$^{-3}$)

If $LKA_{\text{planned}}^{\text{cleared}} > 40\%$ of $A_{B,i,t}^{\text{cleared}}$:

$$
\Delta C_{i,t,\text{init}} = \left[ \frac{44}{12} \times \left( LKP_{\text{unaccounted},i,t} \times C_{ML,i,t} \right) + (MC_{B,AG,i,t} - C_{ML,i,t}) \right] + \frac{E_{B,p,i,t}}{A_{B,i,t}^{\text{cleared}}}
$$

(77)
\[ LKP_{\text{unaccounted,}it} = \frac{LKA_{\text{planned,}it}}{A_{\text{cleared,}it}} - 0.4 \]  

Where:

- \( \Delta C_{it,\text{init}} \) = average initial carbon stock changes and GHG emissions for stratum \( i \) at time \( t \); t CO\(_2\)-e ha\(^{-1}\)

- \( C_{\text{ML,}it} \) = average carbon stocks accounted for as timber emissions under market leakage; t C ha\(^{-1}\)

- \( LKP_{\text{unaccounted,}it} \) = unaccounted proportion of timber emissions not accounted for under market leakage, dimensionless

- \( LKA_{\text{planned,}it} \) = The area of activity shifting leakage at time \( t \); ha

- \( A_{\text{cleared,}it} \) = Area cleared under the baseline scenario for stratum \( i \), in time \( t \); ha

- \( MC_{\text{B,AG,}it} \) = mean carbon stock in above-ground living biomass under the baseline scenario for stratum \( i \), time \( t \); t C ha\(^{-1}\) (Eq. 17)

- \( A_{\text{cleared,}it} \) = Area cleared under the baseline scenario for stratum \( i \), in time \( t \); ha

- \( E_{\text{B,p,}it} \) = total baseline GHG emissions from peat under the baseline scenario in stratum \( i \) at time \( t \); t CO\(_2\)-e (Eq. 56)

In some cases, activities may be displaced to leakage strata that do not exist as baseline strata (e.g., activities are displaced from peat forests to forests on mineral soils), and 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 \( LK=0 \)). In leakage strata that are not included as baseline strata, no timber was to be extracted under the baseline scenario and so \( V_{\text{B,}it} = 0 \), \( C_{\text{B,\text{XBT,}B,}it} = 0 \), and \( LK_{\text{ME,}it} = 0 \). Therefore, \( LK_{\text{AD,}it} \) for leakage strata not included as baseline strata is calculated using the average carbon stock value without a deduction for the carbon stocks in merchantable biomass:

\[ \Delta C_{it,\text{init}} = \left( \frac{44}{12} \times MC_{\text{LK,AG,}it} \right) + \Delta SOC_{it} \]  

Where:

- \( \Delta C_{it,\text{init}} \) = average initial carbon stock changes and GHG emissions for stratum \( i \) at time \( t \); t CO\(_2\)-e ha\(^{-1}\)

- \( MC_{\text{LK,AG,}it} \) = mean carbon stocks in aboveground biomass in leakage stratum \( i \) at time \( t \); t C ha\(^{-1}\)

- \( \Delta SOC_{it} \) = mean change in soil carbon stocks in stratum \( i \) at time \( t \) after conversion to annual cropland; t CO\(_2\)-e ha\(^{-1}\)

\( \Delta SOC_{it} \) can be defined as zero if activities displaced to leakage stratum \( i \) involve clearing land for perennial cropland (e.g., oil palm, rubber, etc.). Where displaced activities involve clearing land for annual cropland, the change in soil carbon stocks in stratum \( i \) at time \( t \) shall be estimated as:
$$\Delta SOC_{it} = \frac{44}{12} \times \left( \frac{C_{soil,it} - (C_{soil,it} \times F_{LU})}{20} \right) \quad (80)$$

Where:

- $\Delta SOC_{it}$ = mean change in soil carbon stocks in stratum $i$ at time $t$ after conversion to annual cropland; t CO$_2$-e ha$^{-1}$
- $C_{soil,it}$ = average soil carbon stocks to 30 cm depth in stratum $i$ at time $t$ before conversion to annual cropland; t C ha$^{-1}$
- $F_{LU}$ = land-use factor for calculating relative soil carbon stock changes; dimensionless

Equation 80 for calculating the change in soil carbon stocks is based on the methodology outlined in Section 5.3.3.4 of the 2006 IPCC AFOLU Guidelines. Only the land use factor is included in Equation 79, and default values for $F_{LU}$ are listed by climate type in Table 5.5 of the IPCC AFOLU Guidelines. Management and input factors are conservatively ignored in this methodology. Average soil carbon stocks in leakage stratum $i$ before conversion to annual cropland shall be estimated using field measurements made in proxy areas or conservative default values from the literature.

**Continued emissions resulting from peat drainage and/or soil carbon loss**

For displaced activities involving conversion to annual cropland on mineral soils or peat drainage, greenhouse gas emissions shall be accounted for beyond the initial year of clearing, because these emissions will continue in years after the initial land use conversion.

Average continued leakage emissions for all strata on peat shall be calculated as:

$$\Delta C_{it,continued} = ME_{B,dd,it} \quad (81)$$

Average continued leakage emissions for all strata on mineral soils that are converted to annual cropland shall be calculated as:

$$\Delta C_{it,continued} = \Delta SOC_{it} \quad (82)$$

Where:

- $\Delta C_{it,continued}$ = average greenhouse gas emissions resulting from continued peat drainage or soil emissions in stratum $i$; t CO$_2$-e ha$^{-1}$.
- $ME_{B,dd,it}$ = mean CO$_2$ emissions from drained peat in stratum $i$, time $t$; t CO$_2$ ha$^{-1}$
- $\Delta SOC_{it}$ = mean change in soil carbon stocks in stratum $i$ at time $t$ after conversion to annual cropland; t CO$_2$-e ha$^{-1}$

$\Delta SOC_{it}$ shall be accounted for in the year of initial clearing as well as the following 19 years. As in the calculation of baseline emissions from peat drainage, emissions from peat drainage in leakage strata can occur only as long as there is a peat supply available to undergo oxidation. Drainage of peat in leakage strata is assumed to occur from the year of initial drainage to $t^\wedge$, where $t^\wedge$ is equal to the number of years after drainage that peat continues to be present assuming a subsidence rate of 4.5 cm yr$^{-1}$. If $t^\wedge$ is greater than the number of years in the project, then drainage shall be included in leakage 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 as leakage only for the number of years in which there is an available supply of peat to undergo oxidation.
Figure 3 below shows how leakage equations are related and indicates in yellow the equations that include at least one parameter for which uncertainty estimation is required.

![Conceptual diagram of leakage equations](image)

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

Figure 3. Conceptual diagram of leakage equations. Equation numbers are shown in parentheses. Yellow boxes indicate equations that include one or more parameters for which uncertainty shall be estimated. In the bottom of the figure, all parameters for which uncertainty must be estimated (or conservative values used) are organized by source.

11. **Ex Ante Net Anthropogenic GHG Emissions Avoided**

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:

\[
C_{REDD} = C_{BSL} - LK \tag{83}
\]

where:

\[C_{REDD} \text{ = net reduction in emissions from deforestation; t CO}_2\text{-e}\]
Note: In this methodology Eq. 83 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.

12. Uncertainties and Conservative Approach

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, use of default values, allometric equations used and methods to combine uncertainties are provided below.

12.1 Uncertainty estimation for individual baseline parameters

This methodology allows for the estimation of uncertainty in emissions and removals associated with REDD project activities. Use of the methodology while planning the project can assure that measurements are of sufficient intensity to minimize uncertainty deductions. Procedures including stratification and the allocation of sufficient measurement plots can help the project to ensure that low uncertainty in carbon stocks results and ultimately full crediting can result. It is good practice to apply this methodology at an early stage to identify the data sources with the highest uncertainty to allow the opportunity to conduct further work to diminish uncertainty. Baseline parameters for which uncertainty shall be assessed are summarized in Figure 2 on page 49.

Uncertainty is defined as the 90% confidence interval as a percentage of the mean:

\[ U_s = \left( \frac{90\% \text{Confidence Interval Width}}{\bar{\mu}} \right) \times 100 \]  

Where:

- \( U_s \) = percentage uncertainty on the estimate of the mean parameter value; %
- \( \bar{\mu} \) = sample mean value of the parameter

A precision target of a 90% confidence interval equal to or less than 10% of the mean recorded value shall be targeted. This is especially important in terms of project planning for measurement of carbon stocks where sufficient measurement plots should be included to achieve this precision level across the measured stocks.

Alternatively, (indisputably) conservative estimates can also be used instead of uncertainties, provided that they are based on verifiable literature sources or expert judgement. In this case the uncertainty is assumed to be zero.

Estimated carbon emissions and removals arising from REDD activities have uncertainties associated with measures/estimates of: area or other activity data, carbon stocks, biomass growth rates, expansion factors, and other coefficients. It is assumed that the uncertainties associated with the estimates of the various input data are available, either as estimates based on sound statistical sampling, default values from well-referenced peer reviewed literature or other well-established published sources, or expert judgement.

12.1.1 Uncertainty in parameters involving 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.

12.1.2 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. Data showing the verification of the allometric equation shall be outlined in the PDD.

12.1.3 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.

Where an uncertainty value is not known or cannot be simply calculated, then a project must justify that it is using an indisputably conservative number and an uncertainty of 0% may be used for this component.

12.1.4 Uncertainty in the Rate of Deforestation

In this methodology, deforestation rates are based on actual deforestation plans by the baseline agent of deforestation, therefore assume the uncertainty of this baseline rate of clearing is zero.

12.1.5 Conservative choice and application of default data

The guidelines provided below should be used to ensure that application of default data in estimation of parameters results in conservative, but not overly conservative, estimates.39

When using default data, the following guidance should be applied when selecting sources of data:

- If an approved A/R CDM or VCS methodology requires application of a default value and provides its numerical value then the value shall be considered as the conservative one;
- Values should if possible be species- or location-specific, with selection from the following data sources (given in order of priority; highest first):
  - Local peer-reviewed studies under similar climate/soil conditions – provided the smaller datasets typical of local studies are considered sufficiently reliable; or
  - Regional or national values for the same ecological zone (that is, the same broad climate zone, and similar soil fertility and type (i.e., peat); or

International or global values, including IPCC literature, for the same ecological zone.

- If species-specific default data are not available, data may be selected from studies in the same ecological zone for the same genus and regarded as conservative. Default data may also be selected from studies in the same ecological zone for the same family, provided the applicability of the data is checked. The priority for selection of default data sources should be that given in the bullet point above.

The guidelines below should be followed to ensure that conservative choice of default data occurs:

a) If default data are available for conditions that are similar to the project, then mean values of the data are considered as conservative;

b) In all other circumstances:
   i. The mean values of default data may be considered as conservative if they have been checked against field measurements and the mean measured data fall within ±10% of the mean default value;
   ii. If the applicability of mean values of default data is not to be verified by field measurement, conservative values of default data should be assessed using the approach provided below:
      - If standard deviation is quoted, then the conservative value is defined as being one standard deviation above (or below, as appropriate) mean values;
      - If a standard error and the number of samples are quoted, then calculate the standard deviation by multiplying the standard error by the square root of the number of samples. The conservative value is defined as being one standard deviation above (or below, as appropriate) mean values;
      - If a range of data is quoted, but without a standard deviation, then assume the range represents the upper and lower 90% confidence limits of a normally distributed dataset. In this case the conservative value is that which falls half way between the mean and the limits of the range;
      - If none of the above area provided, project participants shall use estimates of standard deviations provided in paragraph iii below and assess the conservative value as being one standard deviation above (or below, as appropriate) mean values.

iii. If only mean data are quoted in reports or studies considered to otherwise contain credible data, or if the datasets are small and so it is considered the range of values may not be an adequate estimate of the standard deviation of the particular parameter, the following nominal values should be assumed for standard deviations, expressed here as percentages of the mean (as estimated from the range in IPCC data for these parameters):
   - Aboveground biomass of existing woody vegetation: 50%
   - BEFs of existing woody vegetation based on biomass stocks: -40% below the mean to +100% above

### 12.2 Methods for Combining Uncertainties

#### 12.2.4 Uncertainty of the sum or difference of several terms

The percentage uncertainty on quantities that are the sum or difference of several terms (such as the sum of carbon stocks and greenhouse gas sources in the baseline case) can be estimated using the following simple error propagation equation:\[40\]:

\[40\] Refers to equation 5.2.2 in GPG LULUCF
Uncertainty_{B,it} = \sqrt{\left(\frac{U_{B,SS1,it} \cdot E_{B,it}}{E_{B,SS1,it} + E_{B,SS2,it} + \ldots + E_{B,SSn,it}}\right)^2 + \left(\frac{U_{B,SS2,it} \cdot E_{B,it}}{E_{B,SS1,it} + E_{B,SS2,it} + \ldots + E_{B,SSn,it}}\right)^2 + \ldots + \left(\frac{U_{B,SSn,it} \cdot E_{B,it}}{E_{B,SS1,it} + E_{B,SS2,it} + \ldots + E_{B,SSn,it}}\right)^2}

(85)

Where:

Uncertainty_{B,it} Percentage uncertainty in the combined carbon stocks and greenhouse gas sources in the baseline case in stratum \(i\) at time \(t\); %

\(U_{B,SS,it}\) Percentage uncertainty (expressed as 90% confidence interval as a percentage of the mean where appropriate) for carbon stocks and greenhouse gas sources in the baseline case in stratum \(i\) at time \(t\) (1,2…\(n\) represent different carbon pools and/or GHG sources); %

\(E_{B,SS,it}\) Mean value of carbon stock or GHG sources (e.g. trees, down dead wood, soil organic carbon, emission from biomass burning etc.) in stratum \(i\) at time \(t\) (1,2…\(n\) represent different carbon pools and/or GHG sources) in the baseline case; t CO\(_2\)-e

\(i\) 1, 2, 3 …\(m_{BL}\) strata in the baseline scenario

12.2.5 Uncertainty of the product of several terms

The percentage uncertainties on quantities that are the product of several terms are then estimated using the following equation:\(^{41}\)

\[U_{B,SS,it} = \sqrt{U_1^2 + U_2^2 + \ldots + U_n^2}\]

(86)

Where:

\(U_{B,SS,it}\) = percentage uncertainty (expressed as 90% confidence interval as a percentage of the mean where appropriate) for carbon stocks and greenhouse gas sources in the baseline case in stratum \(i\) (1,2,…\(n\) represent different carbon pools and/or GHG sources); %

\(U_i\) = percentage uncertainties associated with each term of the product (parameters and activity data)\(\),\(i=1,2,\ldots,n\)

The 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.

12.2.6 Estimate of total uncertainty in baseline scenario

Because the uncertainty associated with rates of deforestation are assumed to be zero in the case of planned deforestation, the total uncertainty estimate for each stratum is equal to \(\text{Uncertainty}_{B,it}\) (Eq. 84 above).

To assess uncertainty across combined strata:

---

\(^{41}\) Equation 5.2.1 in GPG LULUCF
Uncertainty\textsubscript{\textit{BSL,t}} = \sqrt{\sum_{i=1}^{mBL} \left( Uncertainty\textsubscript{\textit{B,\textit{i,t}}} * C_{B,\textit{i,t}} \right)^2} \sum_{i=1}^{mBL} C_{B,\textit{i,t}} \tag{87}

where:

- \textit{Uncertainty}\textsubscript{\textit{BSL,t}}: Total uncertainty in baseline scenario at time \textit{t}; %
- \textit{Uncertainty}\textsubscript{\textit{B,\textit{i,t}}}: Uncertainty in baseline scenario in stratum \textit{i} at time \textit{t}; %
- \textit{C}_{\textit{B,\textit{i,t}}}: sum of peat emissions and carbon stock changes in aboveground biomass under the baseline scenario for stratum \textit{i} at time \textit{t}; t CO\textsubscript{2}-e.
- \textit{i}: 1, 2, 3 …\textit{mBL} strata in the baseline scenario

### 13. Data Needed for Ex Ante Estimations

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<td>angle formed between observer’s eye and end of farthest observable canopy branch facing each of eight compass directions or one of two vantage points</td>
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<thead>
<tr>
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<th>( H_{\text{tree}} )</th>
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<tr>
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<td>Meters</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>26, 27, 29</td>
</tr>
<tr>
<td>Description:</td>
<td>height of tree</td>
</tr>
<tr>
<td><strong>Source of data:</strong></td>
<td>Field measurement</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td><strong>Measurement procedures: (if any)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Any comment:</strong></td>
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</tr>
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</tr>
<tr>
<td><strong>Used in equations:</strong></td>
<td>34, 76</td>
</tr>
<tr>
<td><strong>Description:</strong></td>
<td>Mean merchantable volume under the baseline scenario in stratum $i$ at time $t$</td>
</tr>
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<td><strong>Source of data:</strong></td>
<td>Field measurement</td>
</tr>
<tr>
<td><strong>Measurement procedures: (if any)</strong></td>
<td></td>
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<tr>
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<td>Ha</td>
</tr>
<tr>
<td><strong>Used in equations:</strong></td>
<td>40</td>
</tr>
<tr>
<td><strong>Description:</strong></td>
<td>area of biomass growth on future land use in the baseline scenario in stratum $i$ at time $t$</td>
</tr>
<tr>
<td><strong>Source of data:</strong></td>
<td>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</td>
</tr>
<tr>
<td><strong>Measurement procedures: (if any)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Any comment:</strong></td>
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<td><strong>Data unit:</strong></td>
<td>t C ha⁻¹ yr⁻¹</td>
</tr>
<tr>
<td><strong>Used in equations:</strong></td>
<td>42</td>
</tr>
<tr>
<td><strong>Description:</strong></td>
<td>slope of regression line of biomass accumulation function</td>
</tr>
<tr>
<td><strong>Source of data:</strong></td>
<td>Calculated based on field measurements</td>
</tr>
<tr>
<td><strong>Measurement procedures: (if any)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Any comment:</strong></td>
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<td><strong>Data unit:</strong></td>
<td>t C ha⁻¹</td>
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<tr>
<td><strong>Used in equations:</strong></td>
<td>41</td>
</tr>
<tr>
<td><strong>Description:</strong></td>
<td>intercept of regression line</td>
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<td><strong>Source of data:</strong></td>
<td>Calculated based on field measurements</td>
</tr>
<tr>
<td><strong>Measurement procedures: (if any)</strong></td>
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<td><strong>Any comment:</strong></td>
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<tbody>
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</tr>
<tr>
<td><strong>Used in equations:</strong></td>
<td>45</td>
</tr>
<tr>
<td><strong>Description:</strong></td>
<td>age of stand at peak production</td>
</tr>
<tr>
<td><strong>Source of data:</strong></td>
<td>Calculated based on field measurements or literature values</td>
</tr>
<tr>
<td><strong>Measurement procedures: (if any)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Any comment:</strong></td>
<td></td>
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<table>
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<th><strong>Data/parameter:</strong></th>
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<td><strong>Data unit:</strong></td>
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<tr>
<td>Data/parameter:</td>
<td>Description:</td>
</tr>
<tr>
<td>----------------</td>
<td>--------------</td>
</tr>
<tr>
<td>$PBH$</td>
<td>The area cleared at harvest $H$ under the baseline scenario for stratum $i$, in time $t$.</td>
</tr>
<tr>
<td>$PBB_{BH,it}$</td>
<td>The average proportion of aboveground carbon stock removed during harvest $H$ under the baseline scenario for stratum $i$, time $t$.</td>
</tr>
<tr>
<td>$D_B,\text{drain,it}$</td>
<td>The average depth of peat drainage or average depth to water table under the baseline scenario in stratum $i$, time $t$.</td>
</tr>
<tr>
<td>$A_{B,\text{drain,it}}$</td>
<td>The area of drainage impact under the baseline scenario in stratum $i$, time $t$.</td>
</tr>
<tr>
<td>$D_{\text{peat}}$</td>
<td></td>
</tr>
<tr>
<td>Used in equations:</td>
<td>59</td>
</tr>
<tr>
<td>Description:</td>
<td>average depth of peat in project area</td>
</tr>
<tr>
<td>Source of data:</td>
<td>Field measurements</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td></td>
</tr>
<tr>
<td>Any comment:</td>
<td></td>
</tr>
</tbody>
</table>

| Data/parameter: | $D_{B,burn,\text{it}}$ |
| Data unit: | Meters |
| Used in equations: | 63 |
| 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: | $A_{B,\text{burn,\text{it}}}$ |
| Data unit: | Ha |
| Used in equations: | 63 |
| 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: | 63 |
| 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: | 61 |
| Description: | CO$_2$ emissions from the combustion of peat |
| Source of data: | Literature value |
| Measurement procedures: (if any) | |
| Any comment: | |

<p>| Data/parameter: | $EF_{CH4}$ |
| Data unit: | g CH$_4$ (t peat)$^{-1}$ |
| Used in equations: | 62 |
| Description: | CH$_4$ emissions from the combustion of peat |
| Source of data: | Literature value |
| Measurement procedures: (if any) | |
| Any comment: | |</p>
<table>
<thead>
<tr>
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<tr>
<td>Data unit:</td>
<td>t C m(^{-3})</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>67</td>
</tr>
<tr>
<td>Description:</td>
<td>Factor for calculating the biomass of dead wood created during logging operations per cubic meter extracted</td>
</tr>
<tr>
<td>Source of data:</td>
<td>Default value of 0.37 t C m(^{-3}) from 534 logging gaps measured by Winrock International in Bolivia, Belize, Mexico, the Republic of Congo, Brazil and Indonesia may be used for tropical broadleaf forests.</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td></td>
</tr>
<tr>
<td>Any comment:</td>
<td></td>
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<table>
<thead>
<tr>
<th>Data/parameter:</th>
<th>PML(_{FT})</th>
</tr>
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<tbody>
<tr>
<td>Data unit:</td>
<td>%</td>
</tr>
<tr>
<td>Used in equations:</td>
<td></td>
</tr>
<tr>
<td>Description:</td>
<td>Mean merchantable biomass as a proportion of total aboveground tree biomass for each forest types</td>
</tr>
</tbody>
</table>
| Source of data: | The source of data shall be chosen with priority from lower to higher preference as follows:  
1. Peer-reviewed published sources (including carbon/biomass maps or growing stock volume maps with a scale of at least 1 km)  
2. Official government data and statistics  
3. Original field measurements  
The forest types considered shall be only those relevant for the specific market effects leakage i.e. only forest types with active timber production. |
| Measurement procedures: (if any) | |
| Any comment: | |

<table>
<thead>
<tr>
<th>Data/parameter:</th>
<th>(V_{B, it})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data unit:</td>
<td>m(^3)</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>67</td>
</tr>
<tr>
<td>Description:</td>
<td>Volume of timber projected to be extracted from within the project boundary during the baseline in stratum (i) at time (t)</td>
</tr>
<tr>
<td>Source of data:</td>
<td>The source of data shall be chosen with priority from higher to lower preference as follows:</td>
</tr>
</tbody>
</table>
1. Timber harvest records and/or
2. Estimates derived from field measurements and/or
3. Assessments with aerial photography or satellite imagery

**Measurement procedures: (if any)**

**Any comment:** Note that this volume does not include logging slash left onsite. Data compilers should also make sure that extracted volumes reported are gross volumes removed (i.e., reported volume does not already discount for estimated wood waste, as is often the practice of harvest records)

<table>
<thead>
<tr>
<th>Data/parameter:</th>
<th>PMP&lt;sub&gt;i&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data unit:</td>
<td>%</td>
</tr>
<tr>
<td>Used in equations:</td>
<td></td>
</tr>
<tr>
<td>Description:</td>
<td>Merchantable biomass as a proportion of total aboveground tree biomass for stratum &lt;i&gt;i&lt;/i&gt; within the project boundaries</td>
</tr>
<tr>
<td>Source of data:</td>
<td>Within each stratum divide the summed merchantable biomass (defined as total gross biomass (including bark) of a tree 30 cm &lt;i&gt;dbh&lt;/i&gt; or larger from a 30 cm stump to a minimum 10 cm top of the central stem) by the summed total aboveground tree biomass. Merchantable biomass is equal to merchantable volume multiplied by wood density.</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td></td>
</tr>
<tr>
<td>Any comment:</td>
<td>Ex ante a time zero measurement should be made of this factor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data/parameter:</th>
<th>HistHa&lt;sub&gt;i&lt;/sub&gt;</th>
</tr>
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<tbody>
<tr>
<td>Data unit:</td>
<td>Ha</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>71</td>
</tr>
<tr>
<td>Description:</td>
<td>Average annual area of deforestation by the baseline agent of the planned deforestation in stratum &lt;i&gt;i&lt;/i&gt; for the 5-10 years prior to project implementation</td>
</tr>
<tr>
<td>Source of data:</td>
<td>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</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td></td>
</tr>
<tr>
<td>Any comment:</td>
<td></td>
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<table>
<thead>
<tr>
<th>Data/parameter:</th>
<th>A&lt;sub&gt;defLK,i,t&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data unit:</td>
<td>Ha</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>73</td>
</tr>
<tr>
<td>Description:</td>
<td>The total area of deforestation by the baseline agent of the planned deforestation in stratum &lt;i&gt;i&lt;/i&gt; at time &lt;i&gt;t&lt;/i&gt;</td>
</tr>
<tr>
<td>Source of data:</td>
<td>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</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td></td>
</tr>
<tr>
<td>Any comment:</td>
<td>Legal records will include government permits to deforest including concession licenses. Ex-ante, project proponents shall determine and justify the likelihood of leakage based on characteristics of the baseline</td>
</tr>
</tbody>
</table>
agent.
14. Monitoring

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).

15. Monitoring of Project Implementation

The methodology includes 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.

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 foreseen:

- 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 area of each stratum within the project area.

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 the buffer zone is 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

16. Sampling Design and Stratification

The number and boundaries of the strata defined *ex ante* using the methodology procedure outlined in
Section 5 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.

16.1 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 5 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 $A_i$ (area of stratum $i$ at time $t$), which is of utmost importance for an accurate and precise calculation of net anthropogenic GHG emissions avoided.

### 16.2 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.”

### 16.3 Monitoring frequency

Monitoring shall occur annually.

### 16.4 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 8.2.2.1 above).

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

### 17. Calculation of *Ex Post* Net Baseline GHG Emissions

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.

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42 http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-03-v2.pdf
boundary from the time of project validation. However, technical progress and an increase in data availability may occur, allowing for altered baseline estimates.

18. **Data to be Collected and Archived for the Estimation of Net Baseline GHG Emissions**

Under this methodology the data needed for estimating baseline GHG emissions are listed in the section 13 above for calculating *ex ante* baseline net GHG emissions.

19. **Calculation of *Ex Post* Net Actual GHG Emissions Avoided**

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:

$$C_{ACTUAL} = C_{BSL} - C_{PRJ}$$  \hspace{1cm} (88)

where:

- $C_{ACTUAL} = \text{actual net greenhouse gas emissions avoided; t CO}_2\text{-e.}$
- $C_{BSL} = \text{sum of peat emissions and carbon stock changes in aboveground biomass under the baseline scenario; t CO}_2\text{-e}$
- $C_{PRJ} = \text{sum of emissions that occur within the project boundary; t CO}_2\text{-e}$

Note: In this methodology Eq. 87 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.

19.1 **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 8 and are not repeated here.

19.2 **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 $E_{LUC}$ in Eq. 82 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:
\[ C_{PRJ} = \sum_{i=1}^{m} \sum_{t=1}^{T} C_{P, it} \]  
\[ C_{P, it} = E_{P, it}^{\text{logging}} + E_{P, it}^{\text{fire}} + E_{P, it}^{\text{LCC}} \]

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 CO₂-e.
- \( C_{P, it} \) = sum of emissions that occur within the project boundary in stratum \( i \) at time \( t \) as a result of emissions that were unanticipated and/or unable to be avoided by project activities; t CO₂-e.
- \( E_{P, it}^{\text{logging}} \) = GHG emissions due to logging in stratum \( i \), time \( t \); t CO₂-e
- \( E_{P, it}^{\text{fire}} \) = GHG emissions due to fire in stratum \( i \), time \( t \); t CO₂-e
- \( E_{P, it}^{\text{LCC}} \) = GHG emissions due to land use/cover change in stratum \( i \), time \( t \); t CO₂-e
- \( i \) = 1, 2, 3, ..., \( m_{PS} \) strata
- \( t \) = 1, 2, 3, ..., \( t^* \) years

19.2.1 Estimation of GHG emissions due to logging (\( E_{P, it}^{\text{logging}} \))

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)\(^{43}\) and Brown et al. (2006)\(^{44}\).

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:

\[
E_{\text{logging}}^{\text{logging}} = (N_{\text{gaps},i} \cdot EF_{\text{logging},i}) + E_{\text{drainage}}^{\text{drainage}}
\]  

(91)

where:

- \(E_{\text{logging}}^{\text{logging}}\) = GHG emissions due to logging in the project area; t CO\(_2\)-e
- \(N_{\text{gaps},i}\) = number of logging gaps detected in stratum \(i\), time \(t\) in the project area; dimensionless
- \(EF_{\text{logging},i}\) = average logging emission factor for stratum \(i\); t CO\(_2\)-e (logging gap\(^{-1}\))
- \(E_{\text{drainage}}^{\text{drainage}}\) = CO\(_2\) emissions from peat drainage in stratum \(i\) at time \(t\), t CO\(_2\)-e

19.2.1.1 Estimation of \(EF_{\text{logging},i}\)

An average emission factor (\(EF_{\text{logging},i}\)) 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:

\[
EF_{\text{logging},i} = \frac{\sum_{k=1}^{K} C_{P,ik}^{\text{extracted}} + C_{P,ik}^{\text{damaged}}}{K}
\]  

(92)

where:

- \(EF_{\text{logging},i}\) = logging emission factor in stratum \(i\); t CO\(_2\)-e (logging gap\(^{-1}\))
- \(C_{P,ik}^{\text{extracted}}\) = average carbon extracted as timber per logging gap \(k\) in stratum \(i\); t C
- \(C_{P,ik}^{\text{damaged}}\) = 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 \(C_{P,ik}^{\text{damaged}}\) is assumed to be emitted immediately along with \(C_{P,ik}^{\text{extracted}}\). Carbon storage in wood products is conservatively ignored.

To apply Eq. 92 above, field measurements shall be collected to estimate average values of carbon extracted (\(C_{P,ik}^{\text{extracted}}\)) and carbon damaged (\(C_{P,ik}^{\text{damaged}}\)) 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 ($C_{extracted}$)**

**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 ($L_{piece,tr,ik}$, $D_{piece,b,tr,ik}$, $D_{piece,t,tr,ik}$). $L_{log,tr,ik}$ shall be adjusted by subtracting the length of any pieces of bole left on site from the initial distance measured between the stump and crown.

**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:

$$V_{log,tr,ik} = \frac{1}{3} \cdot L_{log,tr,ik} \cdot \pi \left[ \left( \frac{D_{bottom,tr,ik}}{200} \right)^2 + \left( \frac{D_{top,tr,ik}}{200} \right)^2 + \left( \frac{D_{bottom,tr,ik}}{200} \cdot \frac{D_{top,tr,ik}}{200} \right) \right]$$  \hspace{1cm} (93)

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:

$$C_{log,tr,ik} = V_{log,tr,ik} \cdot \phi_i \cdot CF$$  \hspace{1cm} (94)

where:

- $V_{log,tr,ik}$ = volume of log extracted from tree $tr$ in stratum $i$, gap $k$; m$^3$
- $C_{log,tr,ik}$ = biomass carbon of log extracted in stratum $i$, gap $k$; t C
- $\phi_i$ = wood density$^{45}$ of extracted log in stratum $i$, t m$^{-3}$

$^{45}$ 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.
Step 1d. Estimate the total biomass carbon and volume of all commercial logs in gap \( k \):

\[
C_{i,k}^{\text{extracted}} = \sum_{tr=1}^{TR} C_{\log,tr,ik}
\]  

(95)

where:

\( C_{\log,tr,ik} \) = biomass carbon in extracted log of tree \( tr \) in stratum \( i \), gap \( k \); t C

\( C_{i,k}^{\text{extracted}} \) = 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 (\( C_{i,k}^{\text{damaged}} \))

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:

\[
C_{p,ik}^{\text{damaged}} = C_{c+st,ik} + C_{\text{pieces},ik} + C_{\text{incdam},ik}
\]  

(96)

where:

\( C_{p,ik}^{\text{damaged}} \) = total carbon damage caused by logging in stratum \( i \), gap \( k \); t C

\( C_{\text{incdam},ik} \) = incidental carbon damage in stratum \( i \), gap \( k \) due to logged tree; t C

\( C_{c+st,ik} \) = biomass carbon in crown and stump of logged tree in stratum \( i \), gap \( k \); t C

\( C_{\text{pieces},ik} \) = 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:

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

(97)

\[
B_{AG,tr,ik} = f(DBH_{tr,ik}, H_{tr,ik})
\]  

(98)

\[
C_{AG,tr,ik} = \frac{B_{AG,tr,ik} \cdot CF}{1000}
\]  

(99)

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
\[ C_{\text{AG,}\text{tr,}\text{ik}} = \text{aboveground biomass carbon of tree } tr \text{ in stratum } i, \text{ gap } k; \text{ t C} \]
\[ B_{\text{AG,}\text{tr,}\text{ik}} = \text{aboveground tree biomass of tree } tr \text{ in stratum } i, \text{ gap } k; \text{ kg} \]
\[ CF = \text{carbon fraction, t C (t d.m.)}^{-1} \]
\[ D_{s,\text{tr,}\text{ik}} = \text{diameter of the stump of the logged timber tree } tr \text{ in stratum } i, \text{ gap } k; \text{ cm} \]
\[ D_{\text{top,}\text{tr,}\text{ik}} = \text{diameter at the crown end of log extracted from timber tree } tr \text{ in stratum } i, \text{ gap } k; \text{ cm} \]
\[ H_{v,\text{ik}} = \text{tree height of tree } tr \text{ in stratum } i, \text{ gap } k; \text{ m} \]
\[ H_{s,\text{tr,}\text{ik}} = \text{stump height of tree } tr \text{ in stratum } i, \text{ gap } k; \text{ cm} \]
\[ L_{\text{log,}\text{tr,}\text{ik}} = \text{length of log extracted from timber tree } tr \text{ in stratum } i, \text{ gap } k, \text{ measured as the distance from stump to base of crown, less the length of any pieces of bole left on site; m} \]

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

\[ C_{\text{pieces,}\text{tr,}\text{ik}} = \sum_{pce=1}^{PCE} \left[ (0.01 \cdot D_{pce-b,\text{tr,}\text{ik}}) + (0.01 \cdot D_{pce-t,\text{tr,}\text{ik}}) \right] \cdot \pi \cdot L_{pce,\text{tr,}\text{ik}} \cdot \phi_i \cdot CF \] (100)

where:

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

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

\[ C_{\text{pieces,}\text{ik}} = \sum_{tr=1}^{TR} C_{\text{pieces,}\text{tr,}\text{ik}} \] (101)

**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. 91:

\[ C_{c+s,\text{tr,}\text{ik}} = C_{AG,\text{tr,}\text{ik}} - C_{\text{log,}\text{tr,}\text{ik}} - C_{\text{pieces,}\text{tr,}\text{ik}} \] (102)

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

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

\[ C_{c+s,ik} = \sum_{tr=1}^{TR} C_{c+s,tr,ik} \quad (103) \]

where:
\[ C_{c+s,tr,ik} = \text{biomass carbon in crown and stump of logged tree tr in stratum i, gap k; t C} \]
\[ C_{c+s,ik} = \text{biomass carbon in crown and stump of all logged trees in stratum i, gap k; t C} \]
\[ tr = 1, 2, 3, \ldots, TR \text{ timber trees in stratum i, gap k; dimensionless} \]

**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. 90 above) is applied to measurements of dbh of the damaged trees. Total incidental damage is calculated as:

\[ C_{incdam,ik} = \sum_{tr_d=1}^{TR_d} C_{AG,tr_d,ik} \quad (104) \]

and:

\[ C_{AG,tr_d,ik} = \frac{B_{AG,tr_d,ik} \cdot CF}{1000} \quad (105) \]

\[ B_{AG,tr_d,ik} = f(DBH,H) \quad (106) \]

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

19.2.1.3 Estimation of $E_{\text{logging}}^{\text{drainage}}$ (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 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

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46 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.
resulting polygon created in the GIS. This area shall be defined as the area of peat impact \( A_{\text{peatimpact,}it} \) 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 \( A_{\text{peatimpact,}it} \). 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:

\[
E_{\text{drain,}it}^{\text{logging}} = A_{\text{peatimpact,}it}^{\text{logging}} \cdot ME_{\text{drain,}it}^{\text{logging}}
\]

and:

\[
ME_{\text{drain,}it}^{\text{logging}} = f(D_{\text{drain,}it}^{\text{logging}})
\]

where:

- \( E_{\text{drain,}it}^{\text{logging}} \) = CO\(_2\) emissions from peat in stratum \( i \) at time \( t \), t CO\(_2\)-e
- \( A_{\text{peatimpact,}it}^{\text{logging}} \) = area of drainage impact in stratum \( i \), time \( t \); ha
- \( ME_{\text{drain,}it}^{\text{logging}} \) = mean CO\(_2\) emissions from drained peat in stratum \( i \), time \( t \); t CO\(_2\) ha\(^{-1}\)
- \( D_{\text{drain,}it}^{\text{logging}} \) = 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. 100 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\(^{47,48}\) where \( ME_{\text{drain,}it} = 0.91 \cdot D_{\text{drain,}it}^{\text{logging}} \) (or \( ME_{\text{drain,}it} = 9 \) t CO\(_2\) ha\(^{-1}\) 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.

**19.2.2 Estimation of GHG emissions due to fire \( E_{i,\text{fire}} \)\)**

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:

\[ E_{P,\text{fire},it} = A_{P,\text{burn},it} \cdot EF_{\text{fire},it} \]  

(109)

where:

- \( E_{P,\text{fire},it} \) = GHG emissions due to fire in the project area; \( t \) \( \text{CO}_2\)-e
- \( A_{P,\text{burn},it} \) = area burned in stratum \( i \), time \( t \) in the project area; ha
- \( EF_{\text{fire},it} \) = average fire emission factor for stratum \( i \), monitoring year \( t \); \( t \) \( \text{CO}_2\)-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 \( E_{P,\text{fire},it} = 0 \).

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. The area of burning should be tracked directly using an accuracy assessment criterion of 80% or more.

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

An average emission factor \( (EF_{\text{fire},it}) \) 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:

\[ EF_{\text{fire},it} = EF_{P,\text{BiomassBurn},it} + EF_{P,\text{Peatburn},it} \]  

(110)

where:

- \( EF_{\text{fire},it} \) = GHG emissions due to fire in the project area within stratum \( i \), monitoring year \( t \); \( t \) \( \text{CO}_2\)-e ha\(^{-1}\) burnt
\[ EF_{P,\text{BiomassBurn},it} = \text{total increase in } CO_2\text{-e emissions as a result of aboveground biomass burning in stratum } i, \text{ monitoring year } t; \text{ } t CO_2\text{-e } ha^{-1} \text{ burnt} \]

\[ EF_{P,\text{PeatBurn},it} = \text{total increase in } CO_2\text{-e emissions as a result of peat burning in stratum } i, \text{ monitoring year } t; \text{ } t CO_2\text{-e } ha^{-1} \text{ burnt} \]

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

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

\[
EF_{P,\text{BiomassBurn},it} = EF_{P,\text{BiomassBurn},CO_2,itr} + EF_{P,\text{BiomassBurn},N2O,itr} + EF_{P,\text{BiomassBurn},CH4,itr}
\]

(111)

where:

\[ EF_{P,\text{BiomassBurn},CO_2,itr} = \text{CO}_2\text{ emission from biomass burning under the project case in stratum } i, \text{ monitoring year } t; \text{ } t CO_2\text{-e } ha^{-1} \text{ burnt} \]

\[ EF_{P,\text{BiomassBurn},N2O,itr} = N_2O \text{ emission from biomass burning under the project case in stratum } i, \text{ monitoring year } t; \text{ } t CO_2\text{-e } ha^{-1} \text{ burnt} \]

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

and:

\[
EF_{P,\text{BiomassBurn},CO_2,itr} = \left(MC_{B,BB,AG,itr} \cdot PBB_{P,itr} \cdot CE\right) \frac{44}{12}
\]

(112)

where:

\[ PBB_{P,itr} = \text{average proportion of } MC_{B,BB,AG,itr} \text{ burnt under the project case for stratum } i, \text{ time } t; \text{ dimensionless} \]

The CO\(_2\)e emissions resulting from a fire are dependent on the proportion of carbon stocks burned (\( PBB_{P,itr} \)) 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 2.6 of the 2006 IPCC AFOLU Guidelines, which include values for a wider range of vegetation types than values in Table 3.A.14 of IPCC GPG-LULUCF and also give values for both mean and standard deviation. 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:

$$P_{BB} = 1 - \left( MC_{P, A,G, it}^{burned} / MC_{B, B,B, A,G, it} \right)$$  \hspace{1cm} (113)

where:

- $P_{BB} = \text{average proportion of } MC_{B, B,B, A,G, it} \text{ burnt under the project case for stratum } i, \text{ time } t; \text{ dimensionless}$
- $MC_{B, B,B, A,G, it} = \text{estimated aboveground carbon stock in the baseline scenario before burning for stratum } i, \text{ time } t; \text{ t C ha}^{-1}$
- $MC_{P, A,G, it}^{burned} = \text{estimated aboveground carbon stock after burning under the project case for stratum } i, \text{ time } t; \text{ t C ha}^{-1}$

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:

$$EF_{P, BiomassBurn, CO_2, it} = MC_{B, A,G, it} \cdot \frac{44}{12} \hspace{1cm} (114)$$

where:

- $EF_{P, BiomassBurn, CO_2, it} = \text{CO}_2 \text{ emission from biomass burning under the project case for stratum } i, \text{ monitoring year } t; \text{ t CO}_2$-e
- $MC_{B, A,G, it} = \text{average above-ground biomass carbon stock in the baseline scenario for stratum } i, \text{ monitoring year } t; \text{ t C ha}^{-1}$
- $\frac{44}{12} = \text{ratio of molecular weights of CO}_2 \text{ and carbon; dimensionless}$

Non-CO$_2$ emission factors are calculated as:

$$EF_{P, BiomassBurn, N_2O, it} = EF_{P, BiomassBurn, CO_2, it} \cdot \frac{12}{44} \cdot \left( N / Cratio \right) \cdot ER_{N_2O} \cdot \frac{44}{28} \cdot GWP_{N_2O}$$  \hspace{1cm} (115)

$$EF_{P, BiomassBurn, CH_4, it} = EF_{P, BiomassBurn, CO_2, it} \cdot \frac{12}{44} \cdot ER_{CH_4} \cdot \frac{16}{12} \cdot GWP_{CH_4}$$  \hspace{1cm} (116)

where:

- $EF_{P, BiomassBurn, CO_2, it} = \text{CO}_2 \text{ emission from aboveground biomass burning under the project case in stratum } i, \text{ monitoring year } t; \text{ t CO}_2$-e.
- $EF_{P, BiomassBurn, N_2O, it} = N_2O \text{ emission from aboveground biomass burning under the project case in stratum } i, \text{ monitoring year } t; \text{ t CO}_2$-e.
\[ E_{P,\text{BiomassBurn},CH_4,\text{it}} = \text{CH}_4 \text{ emission from aboveground biomass burning under the project case in stratum } i, \text{ monitoring year } t; \text{ t CO}_2\text{-e} \]

\[ N / Cratio = \text{nitrogen-carbon ratio (IPCC default = 0.01); dimensionless} \]

\[ ER_{N_2O} = \text{emission ratio for N}_2\text{O (IPCC default value = 0.007); t CO}_2\text{-e (t C)}^{-1} \]

\[ ER_{CH_4} = \text{emission ratio for CH}_4 \text{ (IPCC default value = 0.012); t CO}_2\text{-e (t CH}_4^{-1} \]

\[ GWP_{N_2O} = \text{Global Warming Potential for N}_2\text{O (= 310 for the first commitment period); t CO}_2\text{-e (t N}_2\text{O)}^{-1} \]

\[ GWP_{CH_4} = \text{Global Warming Potential for CH}_4 \text{ (21 for the first commitment period); t CO}_2\text{-e (t CH}_4^{-1} \]

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 (\( EF_{P,\text{PeatBurn,}\text{it}} \))**

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

\[ EF_{P,\text{PeatBurn,}\text{it}} = EF_{P,\text{PeatBurn},CO_2,\text{it}} + EF_{P,\text{PeatBurn},CH_4,\text{it}} \tag{117} \]

and:

\[ EF_{P,\text{PeatBurn},CO_2,\text{it}} = \frac{M_{P,\text{peat,}\text{it}} \cdot EF_{CO_2}}{10^6} \tag{118} \]

\[ EF_{P,\text{PeatBurn},CH_4,\text{it}} = \frac{M_{P,\text{peat,}\text{it}} \cdot EF_{CH_4} \cdot GWP_{CH_4}}{10^6} \tag{119} \]

\[ M_{P,\text{peat,}\text{it}} = D_{P,\text{burn,}\text{it}} \cdot 10000 \cdot BD_i \tag{120} \]

where:

\[ EF_{P,\text{PeatBurn,}\text{it}} = \text{Total increase in CO}_2\text{-e emissions as a result of peat burning under the project scenario in stratum } i, \text{ time } t; \text{ t CO}_2\text{e} \]

\[ EF_{P,\text{PeatBurn},CO_2,\text{it}} = \text{total CO}_2 \text{ emissions from peat burning under the project scenario in stratum } i, \text{ time } t; \text{ t CO}_2\text{e} \]

\[ EF_{P,\text{PeatBurn},CH_4,\text{it}} = \text{total CH}_4 \text{ emissions from peat burning under the project scenario in stratum } i, \text{ time } t; \text{ t CO}_2\text{e} \]

\[ M_{P,\text{peat,}\text{it}} = \text{mass of peat burned under the project scenario in stratum } i, \text{ time } t; \text{ tons} \]

\[ EF_{CO_2} = \text{CO}_2 \text{ emissions from the combustion of peat, g CO}_2\text{ton peat} \]

\[ EF_{CH_4} = \text{CH}_4 \text{ emissions from the combustion of peat, g CO}_2\text{ton peat} \]

\[ GWP_{CH_4} = \text{Global Warming Potential for CH}_4 \text{ (IPCC default = 21 for the first commitment period); t CO}_2\text{-e (t CH}_4^{-1} \]

\[ M_{P,\text{peat,}\text{it}} = \text{total mass of peat burned under the project scenario in stratum } i, \text{ time } t; \text{ tons} \]

\[ D_{P,\text{burn,}\text{it}} = \text{depth of peat burned under the project scenario in stratum } i \text{ at time } t; \text{ meters} \]

\[ BD_i = \text{bulk density of peat in stratum } i \text{ (g cm}^{-3} = \text{t m}^3) \]
The depth of peat burned \( (D_{\text{burn,pe}}) \) per fire shall be measured in the field or conservatively estimated based on literature values\(^{49}\). 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. \( \text{EF}_{\text{CO}_2} \) and \( \text{EF}_{\text{CH}_4} \) shall be estimated using the baseline methodology outlined in Section 8.2.2.4, Estimation of CO\(_2\) and CH\(_4\) emission factors (\( \text{EF}_{\text{CO}_2}, \text{EF}_{\text{CH}_4} \)).

Muraleedharan et al. (2000)\(^{50}\) measured direct emissions from the combustion of tropical peat at two temperatures (smouldering stage: 480 °C and flaming stage: 600 °C). 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).**

<table>
<thead>
<tr>
<th>Component</th>
<th>Temperature (°C)</th>
<th>g (ton peat)(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>480</td>
<td>600</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>185,000</td>
<td>149,591</td>
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<tr>
<td>CH(_4)</td>
<td>5,785</td>
<td>11,338</td>
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</table>

**19.2.3 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 within the project boundary. The area of deforestation should be tracked directly using an accuracy assessment criterion of 80% or more. 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.

---

49 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.

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

\[
E_{P, it}^{LCC} = \sum_{i=1}^{n} \sum_{t=1}^{m} (A_{P, LCC, it} \cdot EF_{P, LCC, AG, it}) + (A_{\text{peatimpact}}^{LCC} \cdot EF_{\text{peatdrainage}, it})
\]  

(121)

where:

\[
E_{P, it}^{LCC} = \text{GHG emissions due to land cover change in the project area; t CO}_2\text{-e}
\]

\[
A_{P, LCC, it} = \text{area that underwent land cover change in stratum } i, \text{ monitoring year } t; \text{ ha}
\]

\[
A_{\text{peatimpact}}^{LCC} = \text{area of drainage impact due to land cover change in stratum } i, \text{ monitoring year } t; \text{ ha}
\]

\[
EF_{P, LCC, AG, it} = \text{average deforestation emission factor for stratum } i, \text{ monitoring year } t; \text{ t CO}_2\text{-e} \text{ ha}^{-1}
\]

\[
EF_{\text{peat,drainage}, it} = \text{average peat drainage emission factor for stratum } i, \text{ monitoring year } t; \text{ t CO}_2\text{-e} \text{ ha}^{-1}
\]

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. The area of land cover change should be tracked directly using an accuracy assessment criterion of 80% or more. 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\(^{51}\), 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. Calculate the total area of the resulting polygon created in the GIS. This area is defined as the area of peat impact \( A_{\text{peatimpact}}^{LCC} \) 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.

---

\(^{51}\) 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.
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:

\[
EF_{P,LCC,AG,ir} = \frac{44}{12} M_{C,B,AG,ir}
\]

\[
EF_{peat,drainageit} = M_{E,LCC,dd,itt}
\]

and:

\[
M_{E,LCC,dd,itt} = f(D_{drainageit})
\]

where:

- \( EF_{P,LCC,AG,ir} \) = average deforestation emission factor for aboveground emissions in stratum \( i \), monitoring year \( t \); t CO\(_2\)-e ha\(^{-1}\)
- \( EF_{peat,drainageit} \) = average deforestation emission factor for peat drainage in stratum \( i \), monitoring year \( t \); t CO\(_2\)-e ha\(^{-1}\)
- \( M_{C,B,AG,ir} \) = mean carbon stock in above-ground living biomass under the baseline scenario for stratum \( i \), time \( t \); t C ha\(^{-1}\)
- \( M_{E,LCC,dd,itt} \) = 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
- \( D_{drainageit} \) = 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. 8.2.2.1 ‘Estimation of mean carbon stocks in aboveground tree biomass’ for methods on calculating tree biomass.

It is known that the function in Eq. 116 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 \( M_{E,dd,itt} = 0.91D_{drain,itt} \) 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
CO₂ emissions in areas that are expected to be drained >1 meter as per the applicability condition in Section 3.

19.3 Monitoring biomass accumulation in the project area ($\Delta CO₂_{P,LB}$)

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. 5 or Sec. 5.2.2 Sampling Framework for methods on determining plot number, size, and location. See Sec. 8.1.2.1 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):

Figure 4 below shows how monitoring equations are related and indicates in yellow the equations that include at least one parameter for which uncertainty estimation is required.
Figure 4. Conceptual diagram of monitoring equations. Equation numbers are shown in parentheses. Yellow boxes indicate equations that include one or more parameters for which uncertainty shall be estimated. In the bottom of the figure, all parameters for which uncertainty must be estimated (or conservative values used) are organized by source.

20. Data to be Collected and Archived for *Ex Post* Net Actual GHG Emissions Avoided

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<td>$D_{\text{bottom}, i, tr}$</td>
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<td>---------------------------</td>
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<tr>
<td>Used in equations:</td>
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<tr>
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</tr>
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<td>wood density$^{52}$ of extracted log in stratum $i$</td>
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<tr>
<td>Source of data:</td>
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$^{52}$ 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.
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<tr>
<td>Description:</td>
<td>estimated aboveground carbon stock after burning under the project case for stratum $i$, time $t$</td>
</tr>
<tr>
<td>Source of data:</td>
<td>Field measurements</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td>Any comment:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data/parameter:</th>
<th>$N/Cratio$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data unit:</td>
<td>dimensionless</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>115</td>
</tr>
<tr>
<td>Description:</td>
<td>nitrogen-carbon ratio</td>
</tr>
<tr>
<td>Source of data:</td>
<td>IPCC default = 0.01</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
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<thead>
<tr>
<th>Data/parameter:</th>
<th>$ER_{N2O}$</th>
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<tbody>
<tr>
<td>Data unit:</td>
<td>t CO$_2$ e (t C)$^{-1}$</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>115</td>
</tr>
<tr>
<td>Description:</td>
<td>emission ratio for N$_2$O</td>
</tr>
<tr>
<td>Source of data:</td>
<td>IPCC default value = 0.007</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td>Any comment:</td>
</tr>
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<td>Data/parameter:</td>
<td>Description:</td>
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<tr>
<td>----------------</td>
<td>--------------</td>
</tr>
<tr>
<td>$ER_{CH_4}$</td>
<td>emission ratio for CH$_4$</td>
</tr>
<tr>
<td>Data unit:</td>
<td>t CO$_2$-e (t C)$^{-1}$</td>
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<tr>
<td>Used in equations:</td>
<td>116</td>
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<td>Source of data:</td>
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<td>$GWP_{N_2O}$</td>
<td>Global Warming Potential for N$_2$O</td>
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<td>Data unit:</td>
<td>t CO$_2$-e (t N$_2$O)$^{-1}$</td>
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<td>115</td>
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<tr>
<td>Source of data:</td>
<td>(= 310 for the first commitment period)</td>
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<tr>
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<th>Description:</th>
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<td>$GWP_{CH_4}$</td>
<td>Global Warming Potential for CH$_4$</td>
</tr>
<tr>
<td>Data unit:</td>
<td>t CO$_2$-e (t CH$_4$)$^{-1}$</td>
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<tr>
<td>Used in equations:</td>
<td>116, 119</td>
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<tr>
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<td>(= 21 for the first commitment period)</td>
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<th>Description:</th>
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<tbody>
<tr>
<td>$A_{p,burn,i}$</td>
<td>area burned in stratum $i$, time $t$ in the project area</td>
</tr>
<tr>
<td>Data unit:</td>
<td>Ha</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>109</td>
</tr>
<tr>
<td>Source of data:</td>
<td>Field measurements or using high resolution digital aerial imagery</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td></td>
</tr>
<tr>
<td>Any comment:</td>
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<tr>
<th>Data/parameter:</th>
<th>Description:</th>
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<tbody>
<tr>
<td>$D_{p,burn,i}$</td>
<td>depth of peat burned under the project scenario in stratum $i$ at time $t$.</td>
</tr>
<tr>
<td>Data unit:</td>
<td>Meters</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>120</td>
</tr>
<tr>
<td>Source of data:</td>
<td>Field measurements or conservative literature values</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
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</tr>
<tr>
<td>Any comment:</td>
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<th>Description:</th>
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</thead>
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<tr>
<td>$BD_i$</td>
<td>bulk density of peat in stratum $i$</td>
</tr>
<tr>
<td>Source of data:</td>
<td>Field measurements or literature values</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td></td>
</tr>
<tr>
<td>Any comment:</td>
<td></td>
</tr>
<tr>
<td>Data/parameter:</td>
<td>$EF_{CO2}$</td>
</tr>
<tr>
<td>Data unit:</td>
<td>$g$ CO$_2$ (t peat)$^{-1}$</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>118</td>
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<tr>
<td>Description:</td>
<td>CO$_2$ emissions from the combustion of peat</td>
</tr>
<tr>
<td>Source of data:</td>
<td>Literature values</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td></td>
</tr>
<tr>
<td>Any comment:</td>
<td></td>
</tr>
<tr>
<td>Data/parameter:</td>
<td>$EF_{CH4}$</td>
</tr>
<tr>
<td>Data unit:</td>
<td>$g$ CH$_4$ (t peat)$^{-1}$</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>119</td>
</tr>
<tr>
<td>Description:</td>
<td>CH$_4$ emissions from the combustion of peat</td>
</tr>
<tr>
<td>Source of data:</td>
<td>Literature values</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td></td>
</tr>
<tr>
<td>Any comment:</td>
<td></td>
</tr>
<tr>
<td>Data/parameter:</td>
<td>$A_{P,LCC,i,t}$</td>
</tr>
<tr>
<td>Data unit:</td>
<td>Ha</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>121</td>
</tr>
<tr>
<td>Description:</td>
<td>area that underwent land cover change in stratum $i$, monitoring year $t$</td>
</tr>
<tr>
<td>Source of data:</td>
<td>High resolution digital aerial imagery or field measurements</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td></td>
</tr>
<tr>
<td>Any comment:</td>
<td></td>
</tr>
<tr>
<td>Data/parameter:</td>
<td>$A_{LCC_{peatimpact},i,t}$</td>
</tr>
<tr>
<td>Data unit:</td>
<td>Ha</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>121</td>
</tr>
<tr>
<td>Description:</td>
<td>area of drainage impact due to land cover change in stratum $i$, monitoring year $t$</td>
</tr>
<tr>
<td>Source of data:</td>
<td>Calculated in a GIS</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
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</tr>
<tr>
<td>Any comment:</td>
<td></td>
</tr>
<tr>
<td>Data/parameter:</td>
<td>$D_{LCC_{drain},i,t}$</td>
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<td>Data unit:</td>
<td>Cm</td>
</tr>
<tr>
<td>Used in equations:</td>
<td>124</td>
</tr>
<tr>
<td>Description:</td>
<td>average depth of peat drainage or average depth to water table in the deforested area under the project scenario in stratum $i$, time $t$</td>
</tr>
<tr>
<td>Source of data:</td>
<td>Field measurements or estimated from literature values if measurements not available</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td></td>
</tr>
<tr>
<td>Any comment:</td>
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</table>
21. Calculation of Leakage

For leakage calculations and methodology, refer to Section 10 above.

22. Data to be Collected and Archived for Leakage

<table>
<thead>
<tr>
<th>Data/parameter:</th>
<th>Description:</th>
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<tbody>
<tr>
<td>$A^\text{cleared}_{B,t}$</td>
<td>Average annual area of deforestation by the baseline agent of deforestation for the 5 years prior to project implementation</td>
</tr>
<tr>
<td>$A_{\text{defL,K,t}}$</td>
<td>The total area of deforestation by the baseline agent of the planned deforestation at time $t$</td>
</tr>
<tr>
<td>$\text{WoPA}$</td>
<td>Total (cumulative) area of forest cleared by the baseline agent of planned deforestation in stratum $i$ at time $t$</td>
</tr>
<tr>
<td>$\text{HistHa}$</td>
<td>Average annual area of deforestation by the baseline agent of deforestation for the 5 years prior to project implementation</td>
</tr>
</tbody>
</table>
controlled by the baseline agent of deforestation

<table>
<thead>
<tr>
<th>Measurement procedures: (if any)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any comment:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data/parameter:</th>
<th>$PMP_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data unit:</td>
<td>%</td>
</tr>
<tr>
<td>Used in equations:</td>
<td></td>
</tr>
<tr>
<td>Description:</td>
<td>Merchantable biomass as a proportion of total aboveground tree biomass for stratum $i$ within the project boundaries</td>
</tr>
<tr>
<td>Source of data:</td>
<td>Within each stratum divide the summed merchantable biomass (defined as total gross biomass (including bark) of a tree 30 cm dbh or larger from a 30 cm stump to a minimum 10 cm top of the central stem) by the summed total aboveground tree biomass.</td>
</tr>
<tr>
<td>Measurement procedures: (if any)</td>
<td></td>
</tr>
<tr>
<td>Any comment:</td>
<td></td>
</tr>
</tbody>
</table>
23. **Ex Post Net Anthropogenic GHG Emissions Avoided**

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 CO₂-e:

$$C_{REDD} = C_{\text{ACTUAL}} - LK$$

(125)

Where:

- $C_{REDD}$ = net reduced emissions from deforestation; t CO₂-e
- $C_{\text{ACTUAL}}$ = actual net greenhouse gas emissions avoided; t CO₂-e
- $LK$ = leakage; t CO₂-e

Note: In this methodology Eq. 125 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 the calculation of their cumulative values since the starting date of the project activity.

**Calculation of VCU**

To estimate the amount of VCU 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:

$$VCUs = (\text{Adjusted } C_{REDD,2} - \text{Adjusted } C_{REDD,1}) - BRR$$

(126)

Where:

- $VCUs$ = Number of Voluntary Carbon Units
- $\text{Adjusted } C_{REDD,2}$ = Net anthropogenic greenhouse gas emissions avoided (adjusted for uncertainty), as estimated for $t^\# = t_2$; t CO₂-e (Eq. 131)
- $\text{Adjusted } C_{REDD,1}$ = Net anthropogenic greenhouse gas emissions avoided (adjusted for uncertainty), as estimated for $t^\# = t_1$; t CO₂-e (Eq. 131)
- $BRR$ = Portion of carbon credits to be withheld as a buffer reserve

Buffer reserve should be calculated using *VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination*\(^33\).

24. **Accounting for Uncertainties**

\(^33\) Available at: [http://www.v-c-s.org/docs/Tool%20for%20AFOLU%20Non-Permanence%20Risk%20Analysis%20and%20Buffer%20Determination.pdf](http://www.v-c-s.org/docs/Tool%20for%20AFOLU%20Non-Permanence%20Risk%20Analysis%20and%20Buffer%20Determination.pdf)
See Chapter 11.2. ‘Quality control (QC) and quality assurance (QA) procedures to be applied to the monitoring process.

24.1 Uncertainty Ex-Post in the With-Project Scenario

\[
\text{Uncertainty}_{P,i,t} = \sqrt{\left( U_{P,SS1,i,t} \times E_{P,SS1,i,t} \right)^2 + \left( U_{P,SS2,i,t} \times E_{P,SS2,i,t} \right)^2 + \ldots + \left( U_{P,SSn,i,t} \times E_{P,SSn,i,t} \right)^2}
\]

\[
E_{P,SS1,i,t} + E_{P,SS2,i,t} + \ldots + E_{P,SSn,i,t}
\]

(127)

Where:

- \(\text{Uncertainty}_{P,i,t}\) Uncertainty in the with-project scenario in stratum \(i\); %
- \(U_{P,SS,i,t}\) Percentage uncertainty (expressed as 90% confidence interval as a percentage of the mean where appropriate) for carbon stocks, greenhouse gas sources and leakage emissions in the with-project case in stratum \(i\) at time \(t\) (1,2…\(n\) represent different carbon pools and/or GHG sources); %
- \(E_{P,SS,i,t}\) Carbon stock, GHG sources or leakage emission type (e.g. trees, down dead wood, soil organic carbon, emission from fertilizer addition, emission from biomass burning, emission from leakage due to activity shifting etc.) in stratum \(i\) at time \(t\) (1,2…\(n\) represent different carbon pools and/or GHG sources) in the with-project case; t CO₂-e

\(i\) 1, 2, 3 …\(m_{PS}\) strata in the project scenario

\(t\) 1, 2, 3, …\(t^*\) years elapsed since the start of the project activity

To assess uncertainty across combined strata:

\[
\text{Uncertainty}_{P,t} = \sqrt{\sum_{i=1}^{M} \left( \text{Uncertainty}_{P,i,t} \times E_{P,i,t} \right)^2}
\]

\[
\sum_{i=1}^{M} E_{P,i,t}
\]

(128)

\[
E_{P,i,t} = C_{P,i,t} + LK_{AD,i,t} + LK_{ME,i,t}
\]

(129)

Where:

- \(\text{Uncertainty}_{P,t}\) Total uncertainty in project scenario at time \(t\); %
- \(\text{Uncertainty}_{P,i,t}\) Uncertainty in project in stratum \(i\) at time \(t\); %
- \(E_{P,i,t}\) sum of carbon stock, GHG sources and leakage emission types in stratum \(i\) at time \(t\); t CO₂-e.

\(i\) 1, 2, 3 …\(m_{PS}\) strata in the project scenario

\(t\) 1, 2, 3, …\(t^*\) years elapsed since the start of the project activity
24.2 Total Error in REDD Project Activity

\[ C_{REDD\_ERROR,t} = \sqrt{(Uncertainty_{BSL,t} \times C_{BSL,t})^2 + (Uncertainty_{PRJ,t} \times (C_{PRJ,t} + LK_j))^2} \]

\[ C_{BSL,t} + C_{PRJ,t} + LK_j \]

(130)

Where:

- \(C_{REDD\_ERROR,t}\) is the total uncertainty for REDD project activity, \%;
- \(Uncertainty_{BSL,t}\) is the total uncertainty in baseline scenario, \%;
- \(Uncertainty_{PRJ,t}\) is the total uncertainty in the with-project scenario, \%.

24.3 Implications for Project Accounting

The allowable uncertainty under this methodology is +/- 10% of \(C_{REDD,t}\) at the 90% confidence level. Where this precision level is met, no deduction should result for uncertainty. Where uncertainty exceeds 10% of \(C_{REDD,t}\) at the 90% confidence level then the deduction shall be equal to the amount that the uncertainty exceeds the allowable level.

The adjusted value for \(C_{REDD,t}\) to account for uncertainty shall be calculated as:

\[ Adjusted\_C_{REDD,t} = C_{REDD,t} \times \frac{(100 - C_{REDD\_ERROR,t} + 10)}{100} \]

(131)

Where:

- \(C_{REDD,t}\) is net anthropogenic greenhouse emission reductions at time \(t\); t CO₂-e
- \(C_{REDD\_ERROR,t}\) is the total uncertainty for REDD project activity, \%
- \(Adjusted\_C_{REDD,t}\) is the adjusted value for \(C_{REDD,t}\) to account for uncertainty; t CO₂-e

25. Other Information

25.1 Default values used in elaborating the new methodology

- \(CF\) is carbon fraction of dry matter (IPCC default = 0.5); t C (t d.m.)⁻¹
- \(GWP_{N2O}\) is Global Warming Potential for N₂O (IPCC default for the first commitment period = 310 kg); CO₂-e.(kg N₂O)⁻¹
- \(GWP_{CH4}\) is Global Warming Potential for CH₄ (IPCC default for the first commitment period = 21 kg); CO₂-e. (kg CH₄)⁻¹
- \(ER_{N2O}\) is emission ratio for N₂O in biomass burning (IPCC default = 0.007); t CO₂-e. (t C)⁻¹
- \(ER_{CH4}\) is emission ratio for CH₄ in biomass burning (IPCC default = 0.012); t CO₂-e. (t C)⁻¹
- \(CE\) is average combustion efficiency of biomass (IPCC default = 0.5); dimensionless
- \(N/C\) is 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.

25.2 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.

25.2.1 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.

25.2.2 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.

25.2.3 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.

25.2.4 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.

25.2.5 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**

<table>
<thead>
<tr>
<th>QC activity</th>
<th>Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check that assumptions and criteria for the selection of activity data, emission factors and other estimation parameters are documented.</td>
<td>- 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.</td>
</tr>
<tr>
<td>Check for transcription errors in data input and reference.</td>
<td>- Confirm that bibliographical data references are properly cited in the internal documentation.</td>
</tr>
<tr>
<td></td>
<td>- Cross-check a sample of input data from each source category (either measurements or parameters used in calculations) for transcription errors.</td>
</tr>
<tr>
<td>Check that emissions and removals are calculated correctly.</td>
<td>- Reproduce a representative sample of emission or removal calculations.</td>
</tr>
<tr>
<td></td>
<td>- Selectively mimic complex model calculations with abbreviated calculations to judge relative accuracy.</td>
</tr>
<tr>
<td>Check that parameter and units are correctly recorded and that appropriate conversion factors are used.</td>
<td>- Check that units are properly labeled in calculation sheets.</td>
</tr>
<tr>
<td></td>
<td>- Check that units are correctly carried through from beginning to end of calculations.</td>
</tr>
<tr>
<td></td>
<td>- Check that conversion factors are correct.</td>
</tr>
<tr>
<td></td>
<td>- Check that temporal and spatial adjustment factors are used correctly.</td>
</tr>
<tr>
<td>Check the integrity of database files.</td>
<td>- Confirm that the appropriate data processing steps are correctly represented in the database.</td>
</tr>
<tr>
<td></td>
<td>- Confirm that data relationships are correctly represented in the database.</td>
</tr>
<tr>
<td></td>
<td>- Ensure that data fields are properly labeled and have the correct design specifications.</td>
</tr>
<tr>
<td></td>
<td>- Ensure that adequate documentation of database and model structure and operation are archived..</td>
</tr>
<tr>
<td>Check for consistency in data between categories.</td>
<td>- 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.</td>
</tr>
<tr>
<td>Check that the movement of inventory data among processing steps is correct</td>
<td>- Check that emission and removal data are correctly aggregated from lower reporting levels to higher reporting levels when preparing summaries.</td>
</tr>
<tr>
<td></td>
<td>- Check that emission and removal data are correctly transcribed between different intermediate products.</td>
</tr>
<tr>
<td>Check that uncertainties in emissions and removals are estimated or calculated correctly.</td>
<td>- Check that qualifications of individuals providing expert judgment for uncertainty estimates are appropriate.</td>
</tr>
<tr>
<td></td>
<td>- Check that qualifications, assumptions and expert judgments are recorded.</td>
</tr>
<tr>
<td></td>
<td>- Check that calculated uncertainties are complete and calculated correctly.</td>
</tr>
</tbody>
</table>
• 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, recheck estimates and explain the difference.

26. List of Variables Used in Equations

See subsections above for lists of variables.

27. List of Acronyms Used in the Methodology

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AR</td>
<td>Afforestation and Reforestation</td>
</tr>
<tr>
<td>C</td>
<td>Carbon</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>CO₂-e</td>
<td>Carbon dioxide equivalent</td>
</tr>
<tr>
<td>CDM</td>
<td>Clean Development Mechanism</td>
</tr>
<tr>
<td>CF</td>
<td>Carbon fraction</td>
</tr>
<tr>
<td>CH₄</td>
<td>Methane</td>
</tr>
<tr>
<td>d.m.</td>
<td>Dry Matter</td>
</tr>
<tr>
<td>DBH</td>
<td>Diameter at Breast Height</td>
</tr>
<tr>
<td>EB</td>
<td>Executive Board</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
</tr>
<tr>
<td>GPG for LULUCF</td>
<td>Good Practice Guidance for Land Use, Land-use Change and Forestry</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographical Information System</td>
</tr>
<tr>
<td>GPG2000</td>
<td>Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
</tr>
<tr>
<td>H</td>
<td>Tree Height</td>
</tr>
</tbody>
</table>
28. References

All references are cited in footnotes.
<table>
<thead>
<tr>
<th>Version</th>
<th>Date of Issue</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>23 August 2010</td>
<td>Initial version, developed by Infinite Earth, Ltd., was assigned version 6.3 for development purposes and assessed as version 6.3 for reference in the first and second assessment reports. It has been redesignated version 1 for the purposes of finalization and approval by the VCSA.</td>
</tr>
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