VCS | VERIFIED CARBON STANDARD

A Global Benchmark for Carbon

Approved VCS Methodology
VM0012

Version 1.0
Sectoral Scope 14

Improved Forest Management on Privately Owned Properties in Temperate and Boreal Forests (LtPF)

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Table of Contents

1 Sources

The following documents were used to inform and guide the creation of this methodology:

- VCS Standard 2007.1 (Voluntary Carbon Standard, 2008d)
- VCS Program Guidelines 2007.1 (Voluntary Carbon Standard, 2008e)
- VCS Guidance for AFOLU Projects (Voluntary Carbon Standard, 2008a)
- VCS Tool for AFOLU Methodological Issues (Voluntary Carbon Standard, 2008b)
- Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination - Proposed (Voluntary Carbon Standard, 2010a)
- CAR Forest Project Protocol Version 3.0 and 3.2 (Climate Action Reserve, 2010)
- VM0003 Methodology for Improved Forest Management through Extension of Rotation Age, v1.0 (Ecotrust, 2010)

This document structurally follows the proposed 2011 VCS Methodology Template.

2 Summary Description of the Methodology

This document provides a VCS methodology for Improved Forest Management – Logged to Protected Forest projects on land with forests remaining forests and where carbon emission reductions and carbon sequestration occur when logging in the baseline scenario is avoided in the project scenario.

2.1 Baseline and Project Scenario Steps:

1. Determine project eligibility and applicability of this methodology.
2. Establish the project area (= private property boundary).
3. Establish a project time horizon.
4. Determine multiple credible and realistic baseline scenarios.
5. Select the baseline scenario
6. Test for additionality using designated tools and requirements.
7. Select the applicable carbon pools and emission sources for the project area.
8. Create detailed baseline scenario and project scenario assumptions:
   a. Spatially stratify the current land cover and land use conditions by area, if necessary:
   b. Determine the timber harvesting land base area(s)
   c. Project the baseline and project scenario forest management schedule, including forest regeneration practices, for a minimum of one rotation. Include spatially located harvestable volume and area by analysis unit and year, identify stand level harvesting methods and assumptions, and identify additional relevant scenario modeling information.
   d. Project the net annual ecosystem carbon stock changes over time under the baseline and project scenarios, including changes due to harvest removals, regeneration, stand growth, mortality, and any additional factors that materially affect carbon balance.
9. Calculate annualized and project total ex-ante carbon pool flows and GHG Emissions for the baseline and project scenarios.

10. Calculate the net change in GHG emissions between the ex-ante ecosystem carbon projections for the baseline and project scenarios, on an annualized basis.
11. Assess leakage risks to determine a leakage factor to be applied to the net annual GHG emission changes.
12. Calculate and estimate the expected net VCU's, including calculating VCS permanence buffer requirements.
13. Calculate and apply an uncertainty factor to net GHG emission reductions.

2.2 Monitoring Steps:

1. Determine the data and assumptions to be monitored to assess ex-post carbon stock changes in the project area.
2. Determine remote sensing activities for monitoring ex-post land use changes on the project area.
3. Develop and implement a systematic field plot network for estimating and monitoring actual stand level biomass within the project boundary.
4. Develop and implement a leakage monitoring plan.
5. Develop a record-keeping procedure to record and archive monitoring activities, results, and related management actions.
6. Design a quality assurance/quality control program related to monitoring.

3 Definitions

Boreal Forest - as per FAO ecological zone definitions and mapping (FAO, 2001): "The Boreal, or subarctic, domain is found only in the higher latitudes of the Northern Hemisphere between 50-55 to 65-70 degrees. It has at least one and up to 4 month with an average temperature above 10°C. Another feature is the large annual range of temperature. Rainfall is low, generally below 500 mm. The northern boundary, approximately the isotherm of 10°C for the warmest month (usually July), coincides rather well with the poleward limit of tree growth."

Clear cut - Harvest removal of >90% of merchantable trees within a defined area

De minimis – carbon emissions deemed to be insignificant or immaterial to the total GHG calculations. Unless otherwise specified, *de minimis* refers to activities resulting in <5% change in the total project GHG emission reductions. See (CDM, 2007a) for further details.

Fee Simple Land – freehold title and rights are held by a private individual, trust, or corporation (i.e., non-governmental entity). As per VCS: private land/resource rights are where all access and use rights are held by the landowner and the same have not been leased or otherwise granted to a third party which is not a participant in the project activity (Voluntary Carbon Standard, 2010a).

Logging slash - Dead wood residues (including foliage) left on the forest floor after timber removal

Temperate Forest – as per FAO ecological zone definitions and mapping (FAO, 2001): "The temperate domain occupies a medial position within the middle latitudes – usually between the subtropical domain equator-wards and the boreal domain pole-wards. The boundaries with the

subtropical - and boreal domain are 8 months and 4 months, respectively, with average temperatures of 10°C or above. Its main distribution is in the northern hemisphere".

Timber Harvest Land Base (THLB) – a sub-set of the project area land base subject to timber harvesting, including spatially located areas or reasonable volume-based proxies within the project boundaries which are currently considered biologically and economically feasible for timber harvesting as per typical regional logging practices relevant to the project site. Removals from the THLB may include, but are not limited to: non-forest areas; non-commercial forest types; physically inoperable or inaccessible areas due to terrain, soils, etc.; current and future roads and other non-forest clearings; legally required or voluntary buffers and protected areas (i.e. riparian zones, wildlife areas, sensitive sites, etc.), long run uneconomical stands, and other areas which are not eligible for harvesting under typical or common practices determined in the baseline and project scenarios. Examples of determining THLB can be found within British Columbia Timber Supply Analysis documentation at http://www.for.gov.bc.ca/hts/tsas.htm in Timber Supply Area (TSA) Analysis Reports (i.e. pg. 10, http://www.for.gov.bc.ca/hts/tsa/tsa13/tsr2/analysis.pdf); however, projects shall use methods typical of local forest estate modeling and timber supply analyses. Note that the THLB is a primary stratification which identifies areas eligible for harvesting activities, all project requirements apply to the entire project area.

Tree - A perennial woody plant with a diameter at breast height > 5 cm and a height greater than 1.3 m.

Acronyms:

CAR – Climate Action Reserve

CDM - Clean Development Mechanism

GPG LULUCF - Intergovernmental Panel on Climate Change's Good Practice Guidance for Land-Use, Land Use Change and Forestry

IFM - Improved Forest Management (VCS project type)

LtPF – Logged to Protected Forest (VCS IFM project sub-type)

PD - Project Description

VCS - Verified Carbon Standard

VCU - Verified Carbon Units

4   Applicability Conditions

This methodology is applicable to:

1. Projects which meet the most recent approved criteria for VCS Improved Forest Management – Logged to Protected Forest (IFM-LtPF) eligible projects, and;

2. Projects located in Temperate and Boreal Domain Global Ecological Zones (as defined by FAO (FAO, 2001)) which are forest lands remaining forest lands (as defined by IPCC (IPCC, 2003)), and which can meet IPCC GPG LULUCF Tier III inventory and data requirements (IPCC, 2003); and,

3. Projects on fee simple or freehold private ownership properties where the project proponent has clear legal representation of estate title rights without legal title encumbrances that prevent the project from proceeding[1]. Term leases, concessions, or equivalent; public ownership lands; and unknown or legally disputed ownerships are excluded; and,

4. Projects on properties where the *starting* average annual illegal, unplanned, and fuelwood removals are less than 5% of total annual harvest levels (in CO_2e) in the baseline scenario[2]; and,

5. Projects which do not encompass managed peatland forests (peatland as defined by IPCC GPG LULUCF); and,

6. Projects where the total percentage of wetlands in the project area is not expected to change as part of project activities; and,

7. Projects that can demonstrate there will be no activity shifting to other lands owned or managed by project participants outside the project boundary at the beginning of the project (within the first year of the project start date)[3]; and,

8. Projects that do not include non-*de minimis* application of organic or inorganic fertilizer in the project scenario.

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[1] Projects may be considered eligible under this item prior to or during a land acquisition with the provision of valid and binding sales agreements, and the demonstration of no impediments to the carbon rights or carbon project in the seller fee simple title or other transferring legal agreements – the project proponent must gain consent from VCS to proceed with validation, and the project validation will be subject to the sale closing.

[2] This methodology does not provide specific equations and methods for the treatment of illegal and unplanned harvesting or fuelwood removal. Therefore, projects with non-*de minimis* levels (determined using the Tool for Testing Significance of GHG Emissions in A/R CDM Projects (CDM, 2007a)) of these activities in the starting condition (or as local common practice applicable to the project area) are ineligible. If, during the project duration, non-*de minims* levels of illegal and unplanned harvesting or fuelwood removal are found to be occurring, project should to refer the latest VCS AFOLU requirements.

[3] This methodology does not provide specific equations and methods for calculating net emissions related to activity shifting leakage. VCS requires "IFM project developers must demonstrate that there is no leakage within their operations – i.e., on other lands they manage/operate outside the bounds of the VCS carbon project" (Voluntary Carbon Standard, 2008b); and the methodology requires monitoring and reporting on evidence demonstrating no activity shifting is occurring in order to demonstrate compliance with VCS. If, during the project duration, activity shifting is found to be occurring, project should to refer the latest VCS AFOLU requirements.

5 Project Boundary

5.1 Spatial Project Boundaries:

Since this methodology is applicable to private fee-simple properties, the project boundary is to be defined by the project proponent with maps and legal land descriptions, or to defined areas within the legal property boundary(s) owned by the project proponent. Such properties may be contiguous or separate properties if they are located within a similar region and forest condition.

Property areas with unsubstantiated, disputed, or otherwise doubtful or conflicted land ownership are to be excluded.

Note that all spatially relevant forest land holdings owned or managed by the project proponent will need to be considered in leakage assessments and monitoring, even if they are not included in the defined project area.

5.2 Temporal Project Boundaries

As per VCS requirements for AFOLU projects, project proponents must specify a project-crediting as set out in the most recent version of the VCS Standard. .

5.3 Leakage Assessment Boundaries

Leakage within this methodology is assessed against a national leakage area.

5.4 Selected Carbon Pools and Emissions Sources:

Table 1 - Selection of Carbon Pools

Carbon Pool	Selected?	Justification/Explanation
Aboveground Tree Biomass	Yes	Required by VCS. Major carbon pool subject to changes from the baseline to the project scenario.
Aboveground Non-tree Biomass	No	Excluded by VCS. Minor carbon pool subject to changes from the baseline to the project scenario
Belowground Biomass Pool	Yes	Required by VCS. Major carbon pool subject to changes from the baseline to the project scenario.
Dead Wood Pool	Yes	Required by VCS. Minor carbon pool subject to changes from the baseline to the project scenario.
Litter Pool	No	Excluded by VCS for AFOLU projects. Minor carbon pool – generally considered as a transitional pool only.
Soil Carbon Pool	No	Optional in VCS AFOLU IFM projects, but excluded in this methodology. As a conservative approach, changes to soil carbon from harvesting are assumed to be *de minimis*.

Wood Products Pool	Yes		Required by VCS. All baseline scenarios involve logging.

Table 2 - Emissions Sources Included/Excluded from the Project Boundary

Emissions Sources	Gas	Selected?	Justification/Explanation
Use of Fertilizers	CO_2	No	Non-*de minimis* use of fertilizer in the project scenario is excluded. In the baseline scenario, fertilizer emissions are deemed insignificant, as per the VCS May 24th, 2010 AFOLU Program Update (Voluntary Carbon Standard, 2010c). These exclusions are conservative, and do not increase the emission reductions.
	CH_4	No	
	N_20	No	
Combustion of Fossil Fuels by Vehicles / Equipment	CO_2	Yes	Carbon emissions from harvesting equipment, log transport, and primary forest product manufacturing are included. CH_4 and N_2O emissions from equipment are assumed to be *de minimis*. The exclusion of these combustion gases does not increase the emissions reductions in the project.
	CH_4	No	
	N_2O	No	
Burning of Biomass (on site slash burning)	CO_2	No	However, carbon stock decreases due to biomass burning are accounted as a carbon stock change. These exclusion assumptions do not increase the emission reductions in the project.
	CH_4	No	
	N_2O	No	

6 Procedure for Determining the Baseline Scenario:

This methodology utilizes a project-based baseline scenario approach.

The flow of GHG emissions over the project duration is based on the creation and projection of a reasonable, credible, and conservative baseline harvesting scenario in the absence of the carbon project. The most plausible baseline scenario is selected from a comparative assessment of the project and the baseline alternatives, including "at a minimum, a comparative assessment of the implementation barriers and net benefits faced by the project and its alternatives" (Voluntary Carbon Standard, 2008d)

This methodology will employ a 3 step process to select a most likely baseline, and is required to be consistent with the assessment and determination of additionality in Section 7[4]:

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[4] Although only required as part of the Additionality assessment, project proponents may find utilizing the Tool for the Demonstration and Assessment of Additionality in VCS AFOLU Project

STEP 1 – Identify Plausible Alternative Baseline Scenarios to the VCS Project Activity

Project proponents must identify and document descriptions, rationale, and information sources for multiple *(at minimum 3)* realistic and credible property forest management scenarios that would have potentially occurred within the proposed project boundary in the absence of the carbon project activity.

The possible baseline scenarios to be evaluated shall include, at minimum:

1. Historical Practice Baseline Scenarios: continuation of pre-project historical activity baseline or management plans;
2. Common Practice Baseline Scenarios: activity on the project area which could have been performed without the carbon project, based on evidence of comparable forest management for similar property types and situations in the region[5];

All identified baseline scenarios must, at a minimum:

1. Comply with IFM-LtPF project and eligibility requirements by only including activities and areas where forests remain forests;
2. Comply with legal requirements for forest management and land use in the area, "unless verifiable evidence can be provided demonstrating that common practice in the area does not adhere to such requirements" (Voluntary Carbon Standard, 2008a)[6];
3. Demonstrate that the "projected baseline scenario environmental practices equal or exceed those commonly considered a minimum standard among landowners in the area" (Voluntary Carbon Standard, 2008a);

Realistic and credible baseline scenarios shall be based on verifiable information sources such as local or regional land, harvest, or inventory records, observable comparable regional property evidence, formal property appraisals, financial modeling compared against typical published regional industry market return rate targets, regional stakeholder feedback, accredited or certified professionals (i.e. registered professional foresters, etc.) within the regional relevant industry, and other reasonable information sources provided in a manner consistent with typical regional considerations and practices.

Project proponents may utilize tools such as the Investment Analysis (Step 2) and Barrier Analysis (Step 3) of the latest approved version of the VCS Tool for Demonstration and

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Activities (Voluntary Carbon Standard, 2010b) to be useful for additional guidance for identifying and selecting baseline scenarios.

[5] Also considering the financial drivers for management activities based on verifiable market-based financial return expectations of typical market property owners and investors (i.e., IRR, NPV, cost of capital hurdle rates, etc. for data comparisons with available market financial information).

[6] Note that VCS further states: "if it can be shown that these activities result from laws, statutes, regulatory frameworks or policies implemented since 11 November 2001 that give comparative advantage to less emissions-intensive technologies or activities relative to more emissions-intensive technologies or activities they need not be taken into account and the baseline scenario could refer to a hypothetical baseline rate of avoided emissions or sequestration without the national and/or sectoral laws, statutes, regulatory frameworks or policies being in place." (Voluntary Carbon Standard, 2010a).

Assessment of Additionality as an initial filter to exclude project scenarios which are financially infeasible or face clear barriers to implementation.

The remaining baseline scenarios are then further evaluated to select the most likely baseline scenario, as follows.

STEP 2 – Selection of a Single Baseline Scenario for the Project

Project proponents shall select a single baseline scenario for the project using the following steps:

STEP 2a - The Historical Baseline Scenario – based on historical operating practices on the property:

The baseline scenario based on actual property harvest history *must be selected if*:

2a.1   The current property owner retains ownership of the property and has at least 5 years historical harvest level data history[7].

All other cases will utilize the Common Practice Baseline Scenario Selection steps below:

STEP 2b - The Common Practice Baseline Scenario – based on previous owner activities:

2b.1   If the current owner[8] has owned the property for less than five years then the project proponent may:
  i.   Choose to use the previous owners historical activities or management plan as representative of common practice, in which case the baseline scenario is selected based on the process and criteria in Step 2a; *or*,
  ii.   Choose to select the baseline scenario based on common practice and investment analysis of scenarios as outlined in Step 2c below.

STEP 2c - The Common Practice Baseline Scenario – based on new owner activities:

For recent or pending changes in project property ownership without historical data (> 5 years) (or otherwise not selecting a historical baseline scenario as per Step 2b), the project proponent will select the baseline scenario(s) based on an assessment of regional common practice[9] supported by a financial analysis for achieving typical market returns from forest products.

The project proponent shall select the baseline scenario that:

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[7] For convenience, projects may utilize a pre-existing forward-looking forest management plan as the historical baseline data, if this management plan can be demonstrated to be consistent with historical practices and rates, and representative of a forward projection of historical harvest practices.
[8] Including proponents acquiring land as part of the carbon project development, as per footnote 2.
[9] VCS currently defines common practice as: "Extrapolation of observed similar activities in the geographical area with similar socio-economic and ecological conditions as the project area occurring in the period beginning ten years prior to the project start date" (Voluntary Carbon Standard, 2010a).

    2c.1   Generates the most financial attractive return on investment from forest product returns using the assessment process outlined in Step 2 Option II and/or Option III in the most recent version of the VCS [Tool for the Demonstration and Assessment of Additionality in VCS AFOLU Project Activities](#); and,

    2c.2   Can be demonstrated to be regionally common practice and locally operationally implementable, including:

        a. Compliant with the legally required land use and forest management practices in a manner consistent with VCS requirements (see Step 1);

        b. Consistent with local market capacity for the baseline scenario activities and products (i.e. log markets, contractor capacity, etc.);

        c. Consistent with observable and verifiable[10] regional operational practices[11], including, at minimum:

            i.   Harvest types (i.e. clearcut, selective cut, etc.),

            ii. Logging and hauling equipment types and capabilities,

            iii. Annual harvest levels (i.e. m^3/year, ha/year),

            iv. Average minimum harvest age, tree size, and/or stand volume,

            v.   Average minimum economic viability (or decision criteria) by stand type,

            vi. Average minimum log utilization specifications (on average based on size and/or species), and waste/breakage assumptions,

            vii. Average tree retention practices, including hydro-riparian buffers, wildlife trees, and other single or grouped merchantable and un-merchantable tree retention,

            viii. Maximum harvest slope or other operability constraints which would limit regional logging equipment,

            ix. Reforestation and stand management practices; and

        d. Operationally feasible on the project area using local harvesting and hauling technology, local infrastructure, etc. [12].

Project proponents shall provide a description of the selected baseline scenario and related scenario modeling assumptions which justifies and provides supporting evidence that the baseline scenario selected under STEP 2c reflects a credible assessment of typical common practice for similar conditions, as listed above.

STEP 3 – Additionality Test

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[10] Demonstrated by reviewing modeled baseline scenario assumptions in comparison to: directly observable activities on other regional properties, verifiable documentation from previous or current owner operational requirements, property or comparable property appraisals or valuation document assumptions, published documents reviewing regional operational practices, comparable published regional government requirements, testimony of independent local experts and professionals, and/or other verifiable sources.

[11] In the event that regional comparable private fee simple properties are not available, the project proponent may use comparable typical harvest levels and practices from regional government/publically owned forest management areas.

[12] For example, a baseline scenario could not be selected if it involved using equipment (i.e. helicopter logging) not available regionally. A baseline could not be selected which projected a level of harvest the local mills, road infrastructure, and contractor capacity could clearly not physically handle annually without significant additional capital investment. Relevant independent local expert opinion may be used to further demonstrate the reasonableness of local capacity assumptions.

Project proponents must further ensure the selected most plausible baseline scenario is consistent with the outcome of the additionality assessment of this scenario made under Section 7 in this methodology.

7 Procedure for Demonstrating Additionality

Project proponents shall use the newest version of the VCS tool: "Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities". In summary, this tool employs the following steps:

Step 1 - *Identification of alternative land use scenarios to the AFOLU project activity;*

Step 2 - *Investment analysis to determine that the proposed project activity is not the most economically or financially attractive of the identified land use scenarios; or*

Step 3 - *Barriers analysis; and*

Step 4 - *Common practice analysis.*

Project proponents must insure the assessment and outcomes of additionality are consistent with the baseline selection assessment undertaken in Section 6.

8 Baseline Emissions:

The baseline emissions are calculated from the baseline scenario selected in Section 6. This baseline scenario does not change during the project duration, however, as outlined in Section 9.2, certain data or model parameter changes may require remodeling baseline carbon pools in future verifications.

All calculations in this methodology represent annualized net changes in carbon stocks by polygon. Results from each polygon must therefore be summed across the project activity area to determine the annual total net emissions and reductions.

Valid Starting Inventory Requirements

Project proponents must provide a valid starting forest inventory meeting the following requirements:

1. Pertaining directly to the entire project area; and,
2. Created, updated, or validated <10 years ago; and,
3. Documentation is available describing the methods used to create, update, or otherwise validate the starting inventory, including statistical analysis, field data, and/or other evidence[13,14].

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[13] Note that this methodology evaluates uncertainty using actual results from an ex-post plot network program (see Section 11.4) and hence does not mandate a starting inventory accuracy requirement. Project proponents, however, must provide evidence that the starting inventory has been validated to regional common practice minimum standards for use in ex-ante modeling.
[14] Project proponents may provide supporting evidence using local inventory validation results from outside the project area if: they are based on directly comparable inventory methods, overall

Baseline Scenario Area Stratification

The process of stratifying the area represented in the baseline scenario should include two steps. The first is to divide the area (A_{BSL}) into homogeneous units (polygons) from the perspective of carbon storage and sequestration. The second step is to identify areas within the project area that are eligible for specific forest management activities within the baseline and project scenario.

STEP 1 – Stratify to create homogeneous units

If the project activity area is not homogeneous, stratification should be carried out to improve the accuracy and precision of biomass estimates[15]. Different stratifications may be required for the baseline and project scenarios in order to improve accuracy in the estimates of net GHG removal by sinks. For estimation of the baseline net GHG removals by sinks, or calculation of actual net GHG removals, homogeneous *polygons[16] should be defined on the basis of parameters that will be used as key entry variables in the methods used to estimate changes in biomass stocks* (for example, growth models or yield curves/tables). These include:

1. Management regime. For example, types of harvesting (clear cutting, patch retention), and land conversions for roads and landings.
2. Site index / anticipated growth rates
3. Forest species
4. Age class

Useful tools for defining polygons include ground-truthing maps from satellite imagery, aerial photos, and maps of vegetation, soils, and topography.

In the case where a project area is large and spans a diverse range of forest types and ages, the area may need to be stratified into hundreds or even thousands of polygons. When the number of polygons is ≥ 25, the proponent has the option of aggregating similar polygons into "*analysis units[17]*" to facilitate modeling and monitoring. This practice is common when planning management activities over large forest management areas. The use of *analysis units allows polygons to be grouped based on similarities in the polygon criteria, including removing differences associated with stand age*. Each analysis unit is modeled from the period of stand initiation to a mature end point. The attributes (e.g. biomass and dead organic matter pools) of each analysis unit are recorded for every year of growth and stored in a database that can easily be linked back to a specific stand age.

STEP 2 – Identify areas eligible for specific management activities

To assure the project includes only eligible management activities, proponents must identify areas within the project boundary that would be subject to timber harvesting and other

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average forest cover and condition are comparable, and if the data refer to comparable or larger scale properties.

[15] For further details, see
http://cdm.unfccc.int/methodologies/DB/YDYGY2G5VNPKVHB7B9SU12RRWRL439/view.html
[16] At minimum, more than one polygon per project is required for the statistical calculations in Section 11.4.
[17] At minimum, more than one analysis unit is required for the statistical calculations in Section 11.4.

management activities under the baseline scenario. A timber harvesting land base (THLB) should be identified based upon harvesting plans that reflect the historical and future anticipated location and rates of timber extraction. Specific information used to define the THLB should include:

1. The spatial location and extent of forested versus non-forested areas
2. Merchantable and operable forest areas suited to economic timber extraction
3. The spatial location and extent of legal land use restrictions and legally required protected areas.

The THLB is essentially used to refine and focus baseline and project forest management activity projections and modeling, in a manner consistent with the selected scenarios and related common practice.

8.1 Model selection and use

It will be necessary to employ mathematical models to project annual carbon stock changes over time in the various carbon pools. Although it may be possible to utilize a series of spreadsheet calculations for simple forest situations, in most cases complex forest management models (both at the stand and landscape-level) will need to be employed. Regardless of the type of model used, the same model must be used for both the baseline and project scenarios to ensure consistency in the carbon projections.

A hierarchy of suitability should be applied in selecting an appropriate model, in accordance with the following criteria:

1. Well established (i.e., have been under continuous use and development for 10 years, or longer);
2. Generate values on an annual basis (preferably), or at intervals not exceeding 10 years.
3. Include a reasonable representation of mortality from stand-self thinning and natural disturbance agents that are regionally appropriate. Adjustments may need to be made by project proponents to account for these factors if they are not well represented. Rationale must be provided when making adjustments.
4. Output data are expressed in carbon units (tC/ha) or as biomass (t/ha), and are calculated for each of the required carbon pools (See Table 1). If expansion factors are used in combination with growth and yield model(s), they should be based upon regionally specific studies and applied only for the appropriate region and species.
5. Well documented and expert reviewed. In order of preference, these include (a) ongoing publications in peer-reviewed scientific journals, (b) documented reviews by expert practitioners in forestry/biology/ecology, and/or (c) approved by government for use in forest management activities;
6. Parameterized, calibrated, and tested for the specific conditions of the project.

The following criteria are preferred but not required:

7. Documented as appropriate for simulating the ecological and management scenarios that define the baseline and project case;
8. Process-based models that simulate carbon dynamics directly (in the case of stand-level models) or in the case of landscape models (i.e. forest estate models), be driven by

inputs from these stand level models. Process models that simulate all carbon pools within an ecosystem are preferred because their projections of carbon dynamics in the required and optional pools should be more accurate and easier to monitor and verify. Examples of appropriate stand-level growth models include FORECAST ((Kimmins, Mailly, & Seely, 1999), (Seely, Kimmins, Welham, & Scoullar, 1999), and CO2FIX (Masera & et al, 2003)

9. Growth and yield models are commonly used to project productivity in managed and unmanaged forest stands. In most cases their output is in the form of an annual merchantable timber volume increment. Examples include TASS/TIPSY, and VDYP (British Columbia Ministry of Forests and Range[18]), and the US Forest Service's Forest Vegetation Simulator (FVS) model[19]. This approach is less desirable because volume must be converted using a series of expansion factors representing each carbon pool. An example of this approach is the Carbon Budget Model of the Canadian Forest Service (CBM CFS3 (Kurz & et al., 2009), which uses volume curves as input data. For details on the use of expansion factors, see Pearson et al. 2007. This extra step in conversion introduces the potential for additional error into the pool estimates.

In addition, project proponents will make available, at validator/verifier request, documentation of:

1. The appropriateness of the selected model(s) to the particular project application;
2. A listing and explanation of all input data, output data, and model parameters/assumptions.

8.2 Calculating the Baseline Carbon Balance

This methodology employs the IPCC gain-loss method (IPCC, 2006a), which requires the biomass carbon loss be subtracted from the biomass carbon increment for the reporting year. This method is particularly appropriate for areas with a mix of stands of different forest types, and/or where biomass change is very small compared to the total amount of biomass. Further details can be found in (IPCC, 2006a) (Ch. 4).

The total annual carbon balance in year, t, for the baseline scenario is calculated as ($\Delta C_{BSL,t}$, in t C yr^{-1}):

$$\Delta C_{BSL,t} = \Delta C_{BSL,P,t} \tag{1}$$

where:

$\Delta C_{BSL,P,t} = $ annual change in carbon stocks in all pools in the baseline across the project activity area; t C yr^1 .

$$\Delta C_{BSL,P,t} = \Delta C_{BSL,LB,t} + \Delta C_{BSL,DOM,t} + \Delta C_{BSI,HWP,t} \tag{2}$$

where:

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[18] http://www.for.gov.bc.ca/hre/StandDevMod/index.htm
[19] http://www.fs.fed.us/fmsc/fvs/

$\Delta C_{BSL,LB,t}$ = annual change in carbon stocks in living tree biomass (above- and belowground); t C yr^{-1}

$\Delta C_{BSL,DOM,t}$ = annual change in carbon stocks in dead organic matter; t C yr^{-1}

$\Delta C_{BSI,HWP,t}$ = annual change in carbon stocks associated with harvested wood products, t C yr^{-1}.

$$\Delta C_{BSL,LB,t} = \Delta C_{BSL,G,t} - \Delta C_{BSL,i,t} \tag{3}$$

where:

$\Delta C_{BSL,G,t}$ = annual increase in tree carbon stock from growth; t C yr^{-1}

$\Delta C_{BSL,L,t}$ = annual decrease in tree carbon stock from a reduction in live biomass; t C yr^{-1}.

If the project area has been stratified, carbon pools are calculated for each polygon, i, and then summed during a given year, t.

8.2.1 Live Biomass Gain

Live biomass gain in year, *t*, polygon, *i* ($\Delta C_{BSL,G,i,t}$) is calculated as:

$$\Delta C_{BSL,G,t} = \Sigma(A_{BSL,i} \bullet G_{BSL,i,t}) \bullet CF \tag{4}$$

where:

$A_{BSL,i,}$ = area (ha) of forest land in polygon, *i*;

$G_{BSL,i,t}$ = annual increment rate in tree biomass (t d.m. ha^{-1} yr^{-1}), in polygon, *i*, and;

CF = carbon fraction of dry matter t C t^{-1} d.m. (IPCC default value = 0.5).

$$G_{BSL,i,t} = G_{BSL,AG,i,t} + G_{BSL,BG,i,t} \tag{5a}$$

where:

$G_{BSL,AG,i,t}$ and $G_{BSL,BG,i,t}$ = annual above- and belowground biomass increment rates (t d.m. ha^{-1} yr^{-1});

$$G_{BSL,BG,i,t} = G_{BSL,AG,i,t} \bullet R_i \tag{5b}$$

where R_i is the root:shoot ratio in polygon, *i*. R_i should ideally be estimated for each polygon, but these data are difficult to derive empirically. Hence, general relationships are acceptable as long as they are appropriate for the species and region associated with the project (Cairns, 1997).

Equations 4 and 5 can be used directly to calculate $\Delta C_{BSL,G,t}$ when all tree cover within a polygon is removed by harvesting (i.e., clearfelling) and no residual structure is retained. In cases of partial harvesting and/or multiple entries into a polygon, these equations must be applied separately to each of the resulting sub-polygons (the different age classes that are created). This ensures that growth rates reflect the difference in forest age between the sub-polygons.

The ex ante calculation of $G_{BSL,i,t}$ (either directly, or from its component parts) will be derived from models that require inputs derived, in part, from forest inventory data. Criteria for model suitability are provided in 8.1. The exact form of the input data depends on the nature of the model but may include site index, species composition, and volume.

Inventory data used for this purpose must:

1. Pertain directly to the project area, and
2. Not be more than 10 years old.

Typically, inventory data provide only a generalized description of stand attributes such that only average values (versus species-specific estimates) can be used in the ex ante modeling exercise.

Some models will require estimates for parameter values not traditionally measured in typical forest inventories activities. Project proponents shall make reasonable efforts to acquire sources of such data in accordance with the following priority list (best to least desirable):

1. Project area and forest-type specific
2. Regional estimates, from the same or similar ecosystems or forest types
3. National estimates that represent averages for similar forest types
4. Global estimates for generally similar forest types.

8.2.2 Live Biomass Loss

The annual decrease in live biomass tree carbon from live biomass loss ($\Delta C_{BSL,L,t}$; t C yr^{-1}) is the sum of losses from:

1. Natural mortality (i.e. insects, disease, competition, wind, etc.)
2. Commercial round wood felling
3. Incidental sources.

Losses must be specific to a given polygon; each polygon must be summed in order to calculate total annual loss across the project activity area. The live biomass losses are not emitted directly, but rather are transferred to dead organic matter pools.

$$\Delta C_{BSL,L,t} = \Sigma(LBL_{BSL,NATURALi,t} + LBL_{BSL,FELLINGS,i,t} + LBL_{BSL,OTHER,i,t}) \bullet CF \qquad (6)$$

where:

$LBL_{BSL,NATURALi,t}$ = annual loss of live tree biomass due to natural mortality in polygon, i; t d.m. yr^{-1}

$LBL_{BSL,FELLINGS,i,t}$ = annual loss of live tree biomass due to commercial felling in polygon, i; t d.m. yr^{-1}

$LBL_{BSL,OTHER,i,t}$ = annual loss of live tree biomass from incidental sources in polygon, i; t d.m. yr^{-1}

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

$$LBL_{BSL,NATURALi,t} = A_{BSL,i} \bullet LB_{BSL,i,t} \bullet f_{BSL,NATURAL,i,t} \qquad (7)^{20}$$

where

$A_{BSL,i}$ = area (ha) of forest land in polygon, i;

$LB_{BSL,i,t}$ = average live tree biomass (t d.m. ha^{-1}) in polygon, i, for year, t

$LB_{BSL,i,t}$ is calculated for year, t, beginning with biomass estimates in year $t=1$ (the project start year) and with annual biomass increments ($G_{BSL,i,t}$) added as per calculations in equation 5a.

$f_{BSL,NATURAL,i,t}$ = the annual proportion of biomass that dies from natural mortality in polygon , i (unitless; $0 \leq f_{BSL,NATURALi} \leq 1$), year, t. Tree mortality is an ongoing process during stand development. Trees die as a consequence of insect attack, disease, competition, or some combination thereof. Hence, mortality can be highly variable between years. This parameter can be applied uniformly across an analysis unit, or individually to a given polygon. Sources for mortality estimates include permanent sample plots in similar stand types, literature reports, and inventory data.

$$LBL_{FELLINGS,i,t} = A_{BSL,i} \bullet LB_{BSL,i,t} \bullet f_{BSL,HARVEST,i,t} \qquad (8)$$

where:

$A_{BSL,i}$ = area (ha) of forest land in polygon, i

$LB_{BSL,i,t}$ = average live tree biomass (t d.m. ha^{-1}) in polygon, i, for year, t (see equation 7 for its calculation).

$f_{BSL,HARVEST,i,t}$ = the proportion of biomass removed by harvesting from polygon, i, (unitless; $0 \leq f_{BSL,HARVESTli} \leq 1$), in year, t. Data for this variable should be obtained from harvest schedule information. Values may be constrained by (a) the value of $f_{BSL,NATURAL,i,t}$ (i.e., $f_{BSL,HARVEST,i,t} < 1 - f_{BSL,NATURAL,i,t}$), and/or (b) the area of timber available for commercial harvest.

Incidental loss ($LBL_{BSL,OTHER,i,t}$; t d.m. yr^{-1}) is the additional live tree biomass removed for road and landing construction in the polygon, i, and is calculated as a proportion of biomass removed by harvesting:

$$LBL_{BSL,OTHER,i,t} = A_{BSL,i} \bullet LB_{BSL,i,t} \bullet f_{BSL,DAMAGE,i,t} \qquad (9)$$

where:

$A_{BSL,i}$ = area (ha) of forest land in polygon, i;

$LB_{BSL,i,t}$ = average live tree biomass (t d.m. ha^{-1}) in polygon, i, for year, t

$f_{BSL,DAMAGE,i,t}$ = the proportion of additional biomass removed for road and landing construction in polygon, i, year, t (unitless; $0 \leq f_{BSL,DAMAGE,i,t} \leq 1$)[21]. Data for this variable should be based on

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[20] Note, for Equation 7, 8, and 9: $(f_{BSL,NATURAL,i,t} + f_{BSL,HARVEST,i,t} + f_{BSL,DAMAGE,i,t}) \leq 1.0$
[21] Projecting ex-ante road and landing removals beyond a few years is difficult and complex. As described, $f_{BSL,DAMAGE,i,t}$ functions as a proxy for estimating biomass impacts of all new roads and landings associated with

regional and local comparative studies and experiential information derived from the local forest industry[22].

8.2.3 Dead Organic Matter Dynamics ($\Delta C_{BSL,DOM}$)

Dead organic matter (DOM) included in this methodology comprises three components: standing dead wood (minimum $\geq$ 5 cm DBH and 1.3 m height; termed snags), lying dead wood (minimum $\geq$ 5 cm DBH; LDW), and belowground dead wood (i.e., dead roots). Standing dead wood is < 45º of vertical, while lying dead wood is $\geq$ 45º of vertical.

The annual change in carbon stocks in DOM ($\Delta C_{BSL,DOM}$; t C yr^{-1}) is calculated as:

$$\Delta C_{BSL,DOM,t} = \Delta C_{BSL,LDW,t} + \Delta C_{BSL,SNAG,t} + \Delta C_{BSL,DBG,t} \qquad (10)$$

where:

$\Delta C_{BSL,LDW,t}$ = change in lying dead wood (LDW) carbon stocks in year, t; t C yr^{-1}

$\Delta C_{BSL,SNAG,t}$ = change in snag carbon stock in year, t; t C yr^{-1}

$\Delta C_{BSL,DBG,t}$ = change in dead belowground biomass carbon stock in year, t; t C yr^{-1}.

$$\Delta C_{BSL,LDW,t} = \Sigma(LDW_{BSL,IN,i,t} - LDW_{BSL,OUT,i,t}) \bullet CF \qquad (11a)$$

$$LDW_{BSL,i,t+1} = LDW_{BSL,i,t} + (LDW_{BSL,IN,i,t} - LDW_{BSL,OUT,i,t}) \qquad (11b)$$

where:

$LDW_{BSL,,i,t}$ = The total mass of lying dead wood accumulated in polygon i, at time, t (t d.m.).

$LDW_{BSL,IN,i,t}$ = annual increase in LDW biomass for polygon i, year, t (t d.m yr^{-1}). LDW increases occur as a result of natural mortality (typically, blowdown), and as a direct or indirect result of harvesting.

$LDW_{BSL,OUT,i,t}$ = annual loss in LDW biomass through decay, for polygon i, year, t, (t d.m yr^{-1})

$LDW_{BSL,IN,i,t}$ and $LDW_{BSL,OUT,i,t}$ are summed across polygons.

CF = carbon fraction of dry matter (IPCC default value = 0.5).

$$LDW_{BSL,IN,i,t} = (LBL_{BSL,NATURAL,i,t} - LBL_{BSL,NATURAL,i,t} \bullet R_i) \bullet f_{BSL,BLOWDOWN,i,t} +$$

$$((LBL_{BSL,FELLINGS,i,t} - LBL_{BSL,FELLINGS,i,t} \bullet R_i) +$$

$$(LBL_{BSL,OTHER,i,t} - LBL_{BSL,OTHER,i,t} \bullet R_i)) \bullet f_{BSL,BRANCH,i,t} +$$

$$((LBL_{BSL,FELLINGS,i,t} - LBL_{BSL,FELLINGS,i,t} \bullet R_i) +$$

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annual harvesting in polygon, i. Project proponents can simulate $LBL_{BSL,OTHER,i,t}$ directly, if appropriate models are available.

[22] $f_{BSL,DAMAGE,i,t}$ may be zero or de minimis in cases where a polygon is already roaded.

$$(LBL_{BSL,OTHER,i,t} - LBL_{BSL,OTHER,i,t} \bullet R_i)) \bullet$$

$$(1 - f_{BSL,BRANCH,i,t}) \bullet f_{BSL,BUCKINGLOSS,i,t} + SNAG_{BSL,,i,t} \bullet f_{BSL,SNAGFALLDOWN,i,t} \quad (12)$$

where:

$LBL_{BSL,NATURALi,t}$, $LBL_{BSL,FELLINGS,i,t}$, and $LBL_{BSL,OTHER,i,t}$ are as calculated in equations 7, 8, and 9, respectively.

R_i is the root:shoot ratio in polygon, i (see equation 5b).

$f_{BSL,BLOWDOWN,i,t}$ = the annual proportion of live aboveground tree biomass subject to blowdown in polygon, i, year, t (unitless; $0 \leq f_{BSL,BLOWDOWN,i,t} \leq 1$). Ex ante estimates shall be derived preferably from regional reports in similar forest types.

$f_{BSL,BRANCH,i,t}$ = the annual proportion of aboveground tree biomass comprised of branches $\geq$ 5 cm diameter in polygon, i (unitless; $0 \leq f_{BSL,BRANCH,i,t} \leq 1$). Ex ante data are available from allometric equations and models (for example, (Kurz & Apps, 2006) for Canada; (Smith, Miles, Vissage, & Pugh, 2004) for the U.S.). In the event slash burning was undertaken as part of regular management activities, this parameter should be reduced accordingly to reflect the proportion of biomass remaining. Estimates should be obtained from expert opinion; as a default, assume 100% consumption if slash burning occurs.

$f_{BSL,BUCKINGLOSS,i,t}$ = the annual proportion of the log bole biomass left on site after assessing and/or merchandizing the log bole for quality, in polygon, i (unitless; $0 \leq f_{BSL,BUCKINGLOSS,i,t} \leq 1$). Preferably, data for this variable shall be based on regional and local comparative studies and experiential information derived from the local forest industry. Otherwise, an average default value of 21% can be used, based on US national summary statistics(Smith, Miles, Vissage, & Pugh, 2004).

$SNAG_{BSL,,i,t}$ = the total mass of the snag pool in polygon, i, year, t (see equation 14b).

$f_{BSL,SNAGFALLDOWN,i,t}$ = the annual proportion of snag biomass in polygon, i, year, t, that falls over and thus is transferred to the LDW pool (unitless; $0 \leq f_{SNAGFALLDOWN,i,t} \leq 1$). Ex ante estimates for this parameter can be derived from peer reviewed literature (for example, (Parish, Antos, Ott, & Di Lucca, 2010) and forest carbon accounting models that track the rates of input and losses from dead organic matter pools (for example, (Kurz & et al, 2009).

$$LDW_{BSL,OUT,i,t} = LDW_{BSL,,i,t} \bullet f_{BSL,lwDECAY,i,t} \quad\quad\quad (13)$$

where:

$LDW_{BSL,,i,t}$ = the total amount of lying deadwood mass in polygon i, year, t (see equation 11b).
$f_{BSL,lwDECAY,i,t}$ = the annual proportional loss of lying dead biomass due to decay, in polygon i, year, t (unitless; ; $0 \leq f_{BSL,lwDECAY,i,t} \leq 1$). A common approach to ex ante estimation of $f_{BSL,lwDECAY,i,t}$ is to assume mass loss occurs in proportion to the amount of mass remaining in accordance with a single exponential model, of the general form:

$$Y_t = Y_o\, e^{-kt}$$

where Y_o is the initial quantity of material, Y_t the amount left at time t, and k is a decay constant (Harmon, et al., 1986). Other types of exponential models are available (reviewed in (Harmon, et al., 1986)) and may be more appropriate to particular forest types (to be described and justified by the project proponent, if used). Ex ante estimates for the decay parameter appropriate for the project should be derived from peer-reviewed literature (for example, (Harmon, et al., 1986); (Laiho & and Prescott, 2004); (Harmon et al, 2008)).

The change in standing dead wood (snag) carbon stock in year, t (t C yr^{-1}) is calculated as:

$$\Delta C_{BSL,SNAG,t} = \Sigma(SNAG_{BSL,IN,i,t} - SNAG_{BSL,OUT,i,t}) \bullet CF \tag{14a}$$

$$SNAG_{BSL,i,t+1} = SNAG_{BSL,i,t} + (SNAG_{BSL,IN,i,t} - SNAG_{BSL,OUT,i,t}) \tag{14b}$$

where:

$SNAG_{BSL,i,t}$ = The total mass of snags accumulated in polygon *i, at time t (t d.m.).*

$SNAG_{BSL,IN,i,t}$ = annual gain in snag biomass for polygon *i*, year, *t* (t d.m yr^{-1}). Snag biomass develops as a result of natural mortality. In cases where snags are created through management activities, these should be accounted for here.

$SNAG_{BSL,OUT,i,t}$ = annual loss in snag biomass through decay, or falldown (i.e, transfer to the LDW pool)(t d.m yr^{-1})

CF = carbon fraction of dry matter (IPCC default value = 0.5).

Note that $SNAG_{BSL,IN,i,t}$ and $SNAG_{BSL,OUT,i,t}$ are summed across polygons.

$$SNAG_{BSL,IN,i,t} = (LBL_{BSL,NATURALi,t} - LBL_{BSL,NATURALi,t} \bullet R_i) \bullet (1 - f_{BSL,BLOWDOWN,i,t}) \tag{15}$$

where:

$LBL_{BSL,NATURALi,t}$ is as calculated in equation 7, and

$1 - f_{BSL,BLOWDOWN,i,t}$ is the proportion of live tree aboveground biomass that dies in polygon, *i*, year, *t*, but remains as standing dead organic matter (i.e., snags) (unitless; $0 \leq f_{BSL,BLOWDOWN,i,t} \leq 1$). Ex ante default estimates for this calculation can be derived from literature values (for example (Harmon, et al., 1986); (Runkle, 2000); (Harmon et al, 2008)) and should be matched to the ecosystems that most closely characterize the project area.

$$SNAG_{BSL,OUT,i,t} = SNAG_{BSL,i,t} \bullet f_{BSL,SWDECAY,i,t} + SNAG_{BSL,i,t} \bullet f_{BSL,SNAGFALLDOWN,i,t} \tag{16}$$

where:

$SNAG_{BSL,i,t}$ = the total amount of snag mass in polygon *i*, year, *t* (see equation 14b). $f_{BSL,SWDECAY,i,t}$ = the annual proportional loss of snag biomass due to decay, in polygon, *i*, year, *t* (unitless; $0 \leq f_{BSL,SWDECAY,i,t} \leq 1$). As with lying dead wood, a common approach to estimating $f_{BSL,SWDECAY,i,t}$ is to assume mass loss occurs in proportion to the amount of mass remaining in accordance with a single exponential model (see equation 13). Ex ante estimates for this parameter should be derived from peer reviewed literature appropriate for the project site (for example, Vanderwel et al. 2006a) and forest carbon accounting models that track the rates of input and losses from

dead organic matter pools for each forest type, productivity, and age-class (see, for example, Vanderwel et al., 2006b; (Kurz & et al, 2009)).

$f_{BSL,SNAGFALLDOWN,i,t}$ = the annual proportion of snag biomass in polygon, i, that falls over and thus is transferred to the LDW pool (unitless; $0 \leq f_{BSL,SNAGFALLDOWN,i,t} \leq 1$). See equation 12 for parameter estimates.

The annual change in DOM derived from dead belowground biomass ($\Delta C_{BSL,DBG,,t}$; t C yr^{-1}) is calculated for each polygon as per equation 17a. Calculation of $\Delta C_{BSL,DBG,t}$ is specific to a given polygon; each polygon must therefore be summed in order to calculate total annual loss across the project activity area.

$$\Delta C_{BSL,DBG,t} = \Sigma(DBG_{BSL,IN,i,t} - DBG_{BSL,OUT,i,t}) \bullet CF \qquad (17a)$$

$$DBG_{BSL,i,t+1} = DBG_{BSL,i,t} + (DBG_{BSL,IN,i,t} - DBG_{BSL,OUT,i,t}) \qquad (17b)$$

where:

$DGB_{BSL,i,t}$ = The total quantity of dead belowground biomass accumulated in polygon i, at time, t (t d.m.).

$DBG_{BSL,IN,i,t}$ = annual gain in dead belowground biomass for polygon i, year, t (t d.m yr^{-1}). Dead belowground biomass develops as a result of mortality through natural causes or through harvesting activities.

$DBG_{BSL,OUT,i,t}$ = annual loss in dead belowground biomass through decay, (t d.m yr^{-1})

CF = carbon fraction of dry matter (IPCC default value = 0.5).

$$DBG_{BSL,IN,i,t} = [(A_{BSL,i} \bullet LB_{BSL,i,t} \bullet R_i) \bullet$$

$$(f_{BSL,NATURAL,i,t} + f_{BSL,HARVEST,i,t} + f_{BSL,DAMAGE,i,t})] \qquad (17c)$$

where:

$A_{BSL,i}$ = area (ha) of forest land in polygon, i;

$LB_{BSL,i,t}$ = average live tree biomass (t d.m. ha^{-1}) in polygon, i, for year, t. $LB_{BSL,i,t}$ is calculated for year, t, beginning with biomass estimates in year t=1 (the project start year) and with annual biomass increments ($G_{BSL,i,t}$) added as per calculations in equation 5 a, b. This value is then multiplied by $A_{BSL,i}$, the area (ha) of forest land in polygon, i.

R_i is the root:shoot ratio in polygon, i (see equation 5b).

$f_{BSL,NATURAL,i,t}$ = the annual proportion of biomass that dies from natural mortality in polygon, i (unitless; $0 \leq f_{NATURALi} \leq 1$), year, t (see equation 7),

$f_{BSL,HARVEST,i,t}$ = the proportion of biomass removed by harvesting from polygon, i, (unitless; $0 \leq f_{HARVESTIi} \leq 1$), year, t (see equation 8),

$f_{BSL,DAMAGE,i,t}$ = the proportion of additional biomass removed or road and landing construction in polygon, i (unitless; $0 \leq f_{DAMAGE,i,t} \leq 1$), year, t (see equation 9)

$$DBG_{BSL,OUT,i,t} = DBG_{BSL,i,t} \bullet f_{BSL,dgbDECAY,i,t} \tag{17d}$$

where:

$DBG_{BSL,i,t}$ = the total quantity of dead belowground in polygon i, year, t (see equation 17b).

$f_{BSL,dgbDECAY,i,t}$ = the annual proportional loss of dead belowground biomass due to decay, in polygon i, year, t (unitless; ; $0 \leq f_{BSL,lwDECAY,i,t} \leq 1$). The ex ante estimation of the decay of dead belowground biomass should be done using a similar single exponent decay function as that described above for lying deadwood biomass. Estimates for the decay parameter appropriate for specific project should be derived from peer-reviewed literature (see for example: (Moore, Trofymow, Siltanen, Prescott, & CIDET, 2005)); Melin et al. (2009); (Melin, Petersson, & Nordfjell, 2009)).

8.3 Harvested Wood Products

The annual change in the carbon stored in harvested wood products (HWP), $\Delta C_{BSl,HWP,t}$, is calculated as:

$$\Delta C_{BSl,HWP,t} = \Delta C_{BSL,PERMHWP1,t} + \Delta C_{BSL,PERMHWP2,t} - \Delta C_{BSL,EMITFOSSIL,t,} \tag{18}$$

$\Delta C_{BSL,PERMHWP1,t}$ = the annual harvested carbon that remains in permanent storage after conversion to wood products during primary processing (t C yr^{-1})

$\Delta C_{BSL,PERMHWP2,t}$ = carbon that remains in permanent storage after accounting for secondary processing of the residue carbon (biomass) generated from primary processing (t C yr^{-1})

$\Delta C_{BSL,EMITFOSSIL,t}$ = fossil fuel emissions from harvesting (logging and log transport) and processing of the various wood products.

8.3.1 Permanent carbon storage from primary processing ($\Delta C_{BSL,PERMHWP1,t}$)

The IPCC LUCF Sector Good Practice Guideline(IPCC, 2003) for country calculations recommends estimating changes in current stocks of carbon in products-in-use. This approach is not well suited at the project level, however, because of the necessity and difficulty of assembling historical production data, estimating current stocks, and then calculating their relative decay rates. The recommended method is therefore to calculate the long-term storage in HWP stocks attributable to current production. This approach avoids any post-project calculation of carbon emissions associated with product decay, and accounts only for the fraction of wood products in permanent storage over a defined period (100 years is the time frame acceptable to the IPCC) (IPCC, 2000). Application of this 100-year method involves five steps (detailed in (Miner, 2006)):

1. Identify the types and amounts of biomass-based products that are made in the year of interest and end up in a final product.
2. Express this annual production in terms of the amount of biomass carbon per year for each product.

3. Divide the products into categories based on function and allocate the carbon to the functional categories.
4. Use decay curves or other time-in-use information to estimate the fraction of the carbon in each functional category, expected to remain in use for 100 years.
5. Multiply the amount of carbon in annual production in products in each functional category by the fraction remaining at 100 years. The result is the amount of sequestered carbon in the products in each functional category attributable to this year's production.

A variety of equations are available to apply this method (Miner, 2006; see below). Results are sensitive to the selection of time-in-use distributions. Existing time-in-use distributions, many of which have been created to develop national carbon inventories, should be used in the 100-year method only after their suitability for making long-term projections has been established. In some cases, this can be done with available data. Data for U.S. housing, for instance, have been analyzed to confirm that time-in-use information from the U.S. national inventory can be used in the 100-year method without over estimating carbon sequestration(Miner, 2006).

The total carbon in permanent storage from primary processing in year t ($\Delta C_{BSL,PERMHWP1,t}$; t C yr^{-1}) is:

$$\Delta C_{BSL,PERMHWP1,t} = \Sigma[(LBL_{BSL,FELLINGS,i,t} - LBL_{BSL,FELLINGS,i,t} \bullet R_l + LBL_{BSL,OTHER,i,t} -$$
$$LBL_{BSL,OTHER,i,t} \bullet R_l) \bullet (1 - f_{BSL,BRANCH,i,t}) \bullet (1 - f_{BSL,BUCKINGLOSS,i,t})] \bullet$$
$$\Sigma(RE_{BSL,k} \bullet f_{BSL,PERMHWPk}) \bullet CF \quad\quad\quad (19)$$

where:

$LBL_{BSL,FELLINGS,i,t}$ = annual removal of live tree biomass due to commercial felling in polygon, i; t d.m. yr^{-1} (equation 8)

$LBL_{BSL,OTHER,i,t}$ = annual removal of live tree biomass from incidental sources in polygon, i; t d.m. yr^{-1} (equation 9)

$1 - f_{BSL,BRANCH,i,t}$ the proportion of live tree biomass remaining after netting out branch biomass, in polygon i (unitless; $0 \leq f_{BRANCH,i,t} \leq 1$)(see equation 12)

$1 - f_{BSL,BUCKINGLOSS,i,t}$ = the proportion of the log bole remaining after processing for quality, in polygon, i (unitless; $0 \leq f_{BUCKINGLOSS,i,t} \leq 1$) (equation 12)

$RE_{BSL,k}$ = the recovery efficiency for each product type, k (unitless; $0 \leq RE_{BSL,k} < 1$).

CF = carbon fraction of dry matter (IPCC default value = 0.5).

$$RE_{BSL,k} = f_{BSL,PRODUCTk} \bullet f_{BSL,PROCESSk} \quad\quad\quad (20)$$

where:

$f_{BSL,PRODUCTk}$, and $f_{BSL,PROCESSk}$, are the respective fractions allocated to a given forest product type, k, and its associated processing efficiency (unitless; $0 \leq f_{BSL,PRODUCTk}, f_{BSL,PROCESSk} < 1$).

Bucking loss (see equation 12), product allocation, and primary processing efficiency estimates are project specific and may be derived from local or regional average harvesting operations and wood processing facilities when available. Alternatively, project proponents shall select local or regionally appropriate primary processing efficiencies for milling based on published data. One source of information is the CAR Forestry Protocol 3.2, Appendix C (Climate Action Reserve, 2010); national and regional published sources are also available (see for example,(Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005), (Smith, Miles, Vissage, & Pugh, 2004), and references therein).

$f_{BSL,PERMHWPk}$ = the fraction of biomass allocated to permanent storage after a 100-year time period, for each product type, k (unitless; $0 \leq f_{BSLPERMHWPk} < 1$). The simplest (i.e., default) approach is to use a first order decay function, of the following form (Miner, 2006):

$$f_{BSLPERMHWPk} = (1 / (1 + (Ln(2) / HL_k)))^Y \qquad\qquad (21)$$

where:

HL_k is the half-life of a given product type, k (years), and Y is the elapsed time (i.e. 100 years). A number of other more complex decay functions are available (reviewed in (Miner, 2006)). Selection of any particular function other than the default should be justified in the PD. If a first order function is employed, use IPCC (2003a) for default values (see Table 3) unless national or sub-national values are available.

Table 3 - Product half-lives (Miner, 2006)

Product	Half life (years)
Sawnwood	35
Veneer, plywood, structural panels	30
Non-structural panels	20
Paper	2

8.3.2 Secondary processing of the residue carbon (biomass) generated from primary processing ($\Delta C_{BSL,PERMHWP2,t}$)

Primary timber processing mills (facilities that convert roundwood into products such as lumber, plywood, and wood pulp) generate residues that are used for secondary processing. These residues fall into three categories — bark, coarse residues (chunks and slabs), and fine residues (shavings and sawdust). For paper production, Kraft (or sulfate) pulping is the most common processing technology. In Kraft pulping about half the wood is converted into fiber and other half becomes black liquor, a by-product containing unutilized wood fiber and valuable chemicals. Pulp and paper facilities combust black liquor in recovery boilers to produce energy (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005).

The total residual biomass remaining in year t after primary product processing ($B_{BSL,RESIDUAl,t}$; t d.m. yr^{-1}) is:

$$B_{BSL,RESIDUAl,t} = \Sigma[(LBL_{BSL,FELLINGS,i,t} - LBL_{BSL,FELLINGS,i,t} \bullet R_i + LBL_{BSL,OTHER,i,t} -$$

$$LBL_{BSL,OTHER,i,t} \bullet R_i) \bullet (1 - f_{BRANCH,i,t}) \bullet (1 - f_{BSL,BUCKINGLOSS,i,t})] \bullet$$

$$\Sigma(f_{BSL,PRODUCTk} - RE_{BSL,k}) \tag{22}$$

where:

$f_{BSL,PRODUCTk}$ is as defined in equation 20; all other terms are defined in equation 19.

For purposes of secondary manufacturing, it is assumed that any residual biomass derived from paper production (i.e., black liquor) is combusted at 100% efficiency (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005), a conservative assumption. Hence, the final summation term in $B_{RESIDUAl,t}$ is therefore calculated for all product types, except paper.

Let f_{BARK}, f_{COARSE}, and f_{FINE}, be the proportions of bark, coarse, and fine residual biomass, respectively, (unitless; $0 \leq f_{BARKt}$, $f_{COARSEt}$, $f_{FINEt} < 1$) that comprise $B_{BSL,RESIDUAl,t}$. In addition, let $f_{BARKUSE}$, $f_{COARSEUSE}$, and $f_{FINEUSE}$ be the proportions of each of these biomass categories that are allocated to secondary manufacturing (unitless; $0 \leq f_{BARKUSE}$, $f_{COARSEUSE}$, $f_{FINEUSE} < 1$).

The biomass allocated to secondary processing of bark, and coarse and fine residuals, in year, t (t d.m. yr^{-1}), is therefore:

$$B_{BSL,BARK,t} = B_{BSL,RESIDUAl,t} \bullet f_{BSL,BARK} \bullet f_{BSL,BARKUSE} \tag{23a}$$

$$B_{BSL,COARSE,t} = B_{BSL,RESIDUAl,t} \bullet f_{BSL,COARSE} \bullet f_{BSL,COARSEUSE} \tag{23b}$$

$$B_{BSL,FINE,t} = B_{BSL,RESIDUAl,t} \bullet f_{BSL,FINE} \bullet f_{BSL,FINEUSE} \tag{23c}$$

Default values are 26.5%, 42.9%, and 30.6%, for f_{BARK}, f_{COARSE}, and f_{FINE}, respectively (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005). Default values are 85%, and 42%, for $f_{COARSEUSE}$, and $f_{FINEUSE}$, respectively (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005). Evidence indicates that on average 80% of bark is combusted for energy, with the remainder used principally as mulch (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005). Decay rates for mulch are difficult to estimate. Hence, as a default, all bark is assumed to be 100% combusted, a conservative assumption. Local data should be used for all variables, if available.

$B_{COARSE,t}$ and $B_{FINE,t}$ must now be allocated to particular product classes in order to derive estimates of permanence from secondary manufacturing using the 100-year method ($\Delta C_{BSL,PERMHWP2,t}$).

$$\Delta C_{BSL,PERMHWP2,t} = B_{BSL,COARSE,t} \bullet f_{BSL,PROCESSc} \bullet f_{BSL,PERMHWPc} +$$

$$B_{BSL,FINE,t} \bullet f_{BSL,PROCESSf} \bullet f_{BSL,PERMHWPf} \tag{24}$$

Processing efficiencies of coarse and fine residuals ($f_{BSL,PROCESSc}$ and $f_{BSL,PROCESSf}$, respectively) in secondary manufacturing are typically much higher than primary manufacturing. A default

value of 85% can be used (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005) if project-specific values are not available. With respect to calculating permanent storage, the default approach is to assume that $B_{BSL,COARSE,t}$ has a half-life equivalent to sawnwood, and $B_{BSL,FINE,t}$ has a half-life equivalent to non-structural panels (see Table 4). These values are then used in equation 24 to calculate the fraction of biomass allocated to permanent storage after a 100-year time period, for the coarse and fine material. Alternative half-lives (see (Miner, 2006)) can be used if justified from industry-specific information.

8.4 Fossil fuel emissions associated with logging, transport, and manufacture

Annual fossil fuel emissions from harvesting and processing of the various wood products ($C_{BSL,EMITDIRECT,t}$) are calculated as:

$$C_{BSL,EMITFOSSIL,t} = \Delta C_{BSL,EMITHARVEST,t} + \Delta C_{BSL,EMITMANUFACTURE,t} + \Delta C_{BSL,EMITTRANSPORT,t} \qquad (25)$$

where:

$\Delta C_{BSL,EMITHARVEST,t}$ is the annual fossil fuel emissions associated with harvesting of raw material (t C yr^{-1})

$\Delta C_{BSL,EMITMANUFACTURE,t}$ is the annual fossil fuel emissions associated with the manufacturing of raw material (t C yr^{-1})

$\Delta C_{BSL,EMITTRANSPORT,t}$ is the annual fossil fuel emissions associated with the transport of raw material (t C yr^{-1})

The simplest approach to calculating $C_{BSL,EMITFOSSIL,t}$ is to use published or derived carbon emission intensity factors. In the case of harvesting, $\Delta_{BSL,}C_{EMITHARVEST,t}$; t C yr^{-1}), can be calculated as:

$$\Delta C_{BSL,EMITHARVEST,t} = \Sigma[(LBL_{BSL,FELLINGS,i,t} - LBL_{BSL,FELLINGS,i,t} \bullet R_i + LBL_{BSL,OTHER,i,t} - $$

$$LBL_{BSL,OTHER,i,t} \bullet R_i) \bullet (1 - f_{BSL,BRANCH,i,t}) \bullet (1 - f_{BSL,BUCKINGLOSS,i,t})] \bullet$$

$$CF \bullet c_{HARVEST} \qquad (26a)$$

where:

$c_{HARVEST}$ is the carbon emission intensity factor (t C emitted/t C raw material) associated with harvesting (see Table 4 for default values); all other terms are as defined in equation 19.

$\Delta C_{BSL,EMITTRANSPORT,t}$ must be calculated after consideration of the transport distance from harvest to processing facility, and the means of transportation. This term can be calculated as follows (after (Heath, et al., 2010)):

$$\Delta C_{BSL,EMITTRANSPORT,t} = \Sigma[(LBL_{BSL,FELLINGS,i,t} - LBL_{BSL,FELLINGS,i,t} \bullet R_i + $$

$$LBL_{BSL,OTHER,i,t} - LBL_{BSL,OTHER,i,t} \bullet R_i) \bullet (1 - f_{BSL,BRANCH,i,t}) \bullet (1 - f_{BSL,BUCKINGLOSS,i,t})] \bullet$$

$$CF \bullet \Sigma(f_{BSL,TRANSPORTk} \bullet d_{TRANSPORTk} \bullet c_{TRANSPORTk}) \qquad (26b)$$

where:

$f_{BSL,TRANSPORTk}$ = the fraction of raw material transported by transportation type, k. (unitless; $0 \le f_{BSL,TRANSPORTk} < 1$).

$d_{TRANSPORTk}$ = the distance transported by transportation type, k. (km);

$c_{TRANSPORTk}$ is the carbon emission intensity factor (kg C emitted/t C raw material) associated with transportation type, k (see Table 4 for default values); all other terms are as defined in equation 19.

$$\Delta C_{BSL,EMITMANUFACTURE,t} = \Sigma[(LBL_{BSL,FELLINGS,i,t} - LBL_{BSL,FELLINGS,i,t} \bullet R_i + LBL_{BSL,OTHER,i,t} -$$

$$LBL_{BSL,OTHER,i,t} \bullet R_i) \bullet (1 - f_{BSL,BRANCH,i,t}) \bullet (1 - f_{BSL,BUCKINGLOSS,i,t})] \bullet$$

$$\Sigma(f_{BSL,PRODUCTk} \bullet c_{MANUFACTUREk}) \bullet CF \qquad\qquad (27)$$

$c_{MANUFACTUREk}$ is the carbon emission intensity factor (t C emitted/t C raw material) associated with manufacture of product type, k; all other terms are as defined in equation 19.

Default values for $c_{MANUFACTUREk}$ are provided in Table 4. Data are from a comprehensive analysis conducted in Finland (Pingoud, Perälä, Soimakallio, & Pussinen, 2003). Higher comparative values from North America are provided for harvesting and sawnwood manufacturing to illustrate inherent variability. Project proponents may use the default values in Table 4, or substitute regional data, if available.

Table 4 –Carbon emission intensity factors for harvesting, the manufacture of various product categories, k, and for various transportation categories, k.

Activity	Value	Reference	Other (for comparison)
Harvesting ($c_{HARVEST}$) (t C emitted/t C raw material)			
Clearcut harvest	0.016	(Zhang, Cormier, Lyng, Mabee, Ogino, & McLean, 2010)	
Manufacturing ($c_{MANUFACTUREk}$) (t C emitted/t C raw material)			
Sawnwood	0.04	(Pingoud & Lehtila, 2002) – Calculated from Table I & III	0.1 (western US), 0.156 (southern US)(Milota, West, & Hartley, 2005)
Veneer, plywood and structural panels	0.06	(Pingoud & Lehtila, 2002) – Calculated from Table I & III	
Non-structural panels	0.12	(Pingoud & Lehtila, 2002) – Calculated from Table I & III	
Paper		(Pingoud & Lehtila, 2002) – Calculated from Table I & III	
Mechanical pulping	0.48	(Pingoud & Lehtila, 2002) – Calculated from Table I & III	
Chemical pulping	0.13	(Pingoud & Lehtila, 2002) – Calculated from Table I & III	
Transportation ($c_{TRANSPORTk}$) (t C emitted/t C raw material $\bullet$ km)			
Truck	$7.0*10^{-5}$	(Heath, et al., 2010) - From Supporting Information Table S16	
Rail	$8.2*10^{-6}$	(Heath, et al., 2010) - From Supporting Information Table S16	

9   Project Emissions

Net project emissions are calculated by repeating the procedures in Section 8 (Baseline Emissions), using the project scenario polygons, data, and modeling. Unless otherwise noted and justified by the project proponent, all modeling methods, calculations, assumptions, and data sources should be consistent in both the baseline and project scenarios, with the exception of ex-post monitoring data as outlined below. For purposes of efficacy, it may be advantageous to re-stratify the landbase for the project scenario, as compared to the baseline.

Within this methodology, it is anticipated that project scenarios may undertake ongoing low levels of management activities for forest maintenance, ecological enhancement, and/or risk mitigation (for example, pest management, salvage, etc.). In order to comply with the IFM-LtPF project type and this methodology, these activities must meet the following requirements:

1. All net GHG emissions from project activities must be modeled and accounted for in the project scenario in the same manner as the baseline scenario.
2. Project activities cannot remove > 20% of the harvesting volume projected in the baseline scenario over an equivalent 10-year period.
3. Project proponents must be able to demonstrate that activities:
    a. have a conservation benefit and are consistent with principles of managing for biodiversity, ecosystem function, and carbon retention.
    b. are related to restoration, ecological management, or emissions risk reduction

If a project scenario has no planned timber removals, then all related equations in the project emissions calculations in Section 9 can be set to zero.

If the project scenario has planned activities other than those involving the removal of timber that affect non-*de minimis* levels of carbon stock, the project must document these activities, reasonably calculate their carbon impacts, and include these emissions in the total carbon calculations for the project scenario.

All calculations in this methodology represent annualized net changes in carbon stocks by polygon, which must therefore be summed across the project activity area to determine the annual total net emissions and reductions.

Note, additional details for many calculations, including references and background are provided within the equivalent Baseline Emissions section.

9.1   Project Scenario Area Stratification

The project scenario will utilize the same methods and steps to create polygons as outlined for the baseline scenario (see Section 8) from $A_{PRJ,I}$. However, the project scenario may be stratified differently to accommodate different project management activities and/or changes to inventory data resulting from ex-post monitoring (if new polygons are created as the result of natural disturbance events, for example). There may be differences between the project and baseline scenarios in the areas within the landbase that are eligible for specific forest management activities (i.e., the assumptions used to determine the THLB may differ in the project scenario relative to the baseline). However, the underlying inventory and data assumptions must be the same in the baseline and project scenarios.

9.2 Determining Actual Onsite Carbon Stocks

Actual carbon stocks must be calculated prior to each verification, or at a maximum interval of 5 years, by updating the project's forest carbon inventory from the monitoring data.

This is done by:

1. Incorporating any new forest inventory data (including data from new or re-measured sampling plots and other monitored data, as outlined in Section 13 and 14) obtained during the previous year into the inventory estimate.
2. Updating the forest inventory for spatial monitoring results, including annual project activities and/or disturbances that have occurred during the monitoring period.
3. Using the selected model(s) to project prior-year data from the forest inventory to the current reporting year (as described in Section 9.3).
4. Comparing estimates of live biomass and dead organic matter in polygons and calculated from monitoring activities (Section 13 and 14) against current-year modeled values in the project scenario (see Section 9.2.2).
5. Making calibration adjustments to models and/or parameters such that the fit between the equivalent modeled and measured variables meets targets (as per Section 9.2.2).
6. If any changes are made to the model assumptions or parameters used in Section 9, the calculation of baseline emissions (from the current date forward) must be redone using the updated model(s) and parameter sets.
7. Calculate the error terms for use in determining the uncertainty factor (Section 11.4).

9.2.1 Ex-Post Calculations of Carbon Stocks

Actual (ex post) annual net carbon stocks are calculated using the equations in this section.

$$C_{ACTUAL,i,t} = C_{LB,i,t} + C_{DOM,i,t} \hspace{2cm} \text{(28a)}$$

where:

$C_{ACTUAL,i,t}$ = carbon stocks in all selected carbon pools in polygon, i, year, t; t C

$C_{LB,i,t}$ = carbon stocks in living tree biomass in polygon, i, year, t; t C

$C_{DOM,i,t}$ = carbon stocks in dead organic matter in year, t; t C

Live biomass

Average aboveground biomass for measured polygon, i, in year, t ($B_{AG,i,t}$) is determined by converting the aboveground, tree-level measurements (kg biomass per tree) described in Section 13.2 to area-based, stand-level measurements (t ha^{-1}). This is achieved by summing the aboveground biomass of all the trees within a sample plot, converting kg to t, and then dividing the sum by the plot area in ha. All plots within a particular polygon should be averaged to get an average estimate of stand-level aboveground biomass (t ha^{-1}). Once the average aboveground biomass has been determined for each measured polygon, belowground biomass is estimated by multiplying the aboveground biomass by the root:shoot ratio, R_i (equation 28d) and the two are summed to determine total stand-level live biomass for measured polygon i, time t, ($B_{TOTAL,i,t}$). R_i is described in Section 8.2.1. Finally, the average measured carbon stock in

living tree biomass for measured polygon i, time t, ($C_{LB,i,t}$) is calculated as shown in equation 28c. This value of $C_{LB,i,t}$ must be compared to the equivalent calculation of live biomass ($LB_{PRJ,i,t}$) calculated in the project scenario (Section 9.3) (see comparison method and steps below).

$$B_{TOTAL,i,t} = (B_{AG,i,t} + B_{BG,i,t}) \qquad\qquad\qquad (28b)$$

$$C_{LB,i,t} = (B_{TOTAL,i,t}) \bullet CF \qquad\qquad\qquad (28c)$$

where:

$B_{AG,i,t}$ = aboveground tree biomass (t d.m. ha^{-1}) measured in polygon, i, year, t

$B_{BG,i,t}$ = belowground tree biomass (t d.m. ha^{-1}) measured in polygon, i, year, t.

$B_{TOTAL,i,t}$ = total tree biomass (t d.m. ha^{-1}) measured in polygon, i, year, t

$$B_{BG,i,t} = B_{AG,i,t} \bullet R_i \qquad\qquad\qquad (28d)$$

CF = carbon fraction of dry matter (IPCC default value = 0.5)

Dead organic matter

Carbon stored in dead organic matter pools in measured polygon, i, year t, ($C_{DOM,i,t}$) is calculated as the sum of that stored in lying dead wood and standing snags.

$$C_{DOM,i,t} = (DOM_{LDW,i,t} + DOM_{SNAG,i,t}) \bullet CF \qquad\qquad (28e)$$

where:

$DOM_{LDW,i,t}$ = average mass of dead organic matter contained in lying dead wood (t d.m. ha^{-1}) in measured in polygon, i, year, t

$DOM_{SNAG,i,t}$ = average mass of dead organic matter contained in standing snags (t d.m. ha^{-1}) in measured in polygon, i, year, t

The average quantity of dead organic matter contained in lying dead wood for measured polygon, i, in year, t ($DOM_{LDW,i,t}$) is calculated according to equations 60a-c in Section 13.2. The value of $DOM_{LDW,i,t}$ must be compared to the equivalent calculation of lying dead wood mass ($LDW_{PRJ,i,t}$) in the project scenario (Section 9.3.3) (see comparison method and steps below).

The average quantity of dead organic matter contained in standing snags for measured polygon, i, in year, t ($DOM_{SNAG,i,t}$ is calculated by summing the mass (aboveground only) of all the measured standing dead trees within a sample plot (converting kg to t) and dividing the sum by the plot area in ha (See Section 13.2). The belowground component of snags is treated as dead belowground biomass (See Section 9.3.3) and is not directly measured. All plots within a particular polygon should be averaged to get an average estimate of $DOM_{SNAG,i,t}$. The value of $DOM_{SNAG,i,t}$ must be compared to the equivalent calculation of standing dead tree mass ($SNAG_{PRJ,i,t}$) in the project scenario (Section 9.3.3) (see comparison method and steps below).

9.2.2 Updating the Modeled Project Carbon Balance

In this methodology, the ex ante carbon balances in the project case may be derived from computer model output. In this event, the precision of the modeled carbon stocks should be evaluated for each polygon or analysis unit (depending on the level of stratification used) using the method described for determining mean model error in Section 11.4 (equations 60a,b). If the model error term is too high (> 10%), proponents should attempt to improve the model fit by re-evaluating and adjusting model parameters until model error term is < 10%. Model error terms greater than 10% (after model adjustments) will be penalized according the calculation of the uncertainty factor described in Section 11.4. If changes in model assumptions or parameters are made, the baseline scenario (from the next year forward) must be recalculated using the revised model.

9.3 Calculating the Project Carbon Balance

The total annual carbon balance in year, t, for the project scenario is calculated as ($\Delta C_{PRJ,t}$, in t C yr^{-1}):

$$\Delta C_{PRJ,t} = \Delta C_{PRJ,P,t} \qquad\qquad (29)$$

where:

$\Delta C_{PRJ,P,t}$ is the annual change in carbon stocks in all pools in the project across the project activity area; t C yr^{-1} .

$$\Delta C_{PRJ,P,t} = \Delta C_{PRJ,LB,t} + \Delta C_{PRJ,DOM,t} + \Delta C_{PRJ,HWP,t} \qquad\qquad (30)$$

$\Delta C_{PRJ,LB,t}$ = annual change in carbon stocks in living tree biomass (above- and belowground); t C yr^{-1}

$\Delta C_{PRJ,DOM,t}$ = annual change in carbon stocks in dead organic matter; t C yr^{-1}

$\Delta C_{PRJ,HWP,t}$ is the annual change in carbon stocks associated with harvested wood products, t C yr^{-1}.

$$\Delta C_{PRJ,LB,t} = \Delta C_{PRJ,G,t} - \Delta C_{PRJ,L,t} \qquad\qquad (31)$$

where:

$\Delta C_{PRJ,G,t}$ = annual increase in tree carbon stock from growth; t C yr^{-1}

$\Delta C_{PRJ,L,t}$ = annual decrease in tree carbon stock from a reduction in live biomass; t C yr^{-1}.

If the project area has been stratified, carbon pools are calculated for each polygon, i, and then summed during a given year, t.

9.3.1 Live Biomass Gain

Live biomass gain in year, *t*, polygon, *i* ($\Delta C_{PRJ,G,i.t}$) is calculated as:

$$\Delta C_{PRJ,G,t} = \Sigma(A_{PRJ,i} \bullet G_{PRJ,i,t}) \bullet CF \qquad\qquad (32)$$

where:

$A_{PRJ,i,}$ = area (ha) of forest land in polygon, i;

$G_{PRJ,i,t}$ = annual increment rate in tree biomass (t d.m. ha^{-1} yr^{-1}), in polygon, i, and;

CF = carbon fraction of dry matter t C t^{-1} d.m. (IPCC default value = 0.5).

$$G_{PRJ,i,t} = G_{PRJ,AG,i,t} + G_{PRJ,BG,i,t} \qquad\qquad (33a)$$

where $G_{PRJ,AG,i,t}$ and $G_{PRJ,BG,i,t}$ are the annual above- and belowground biomass increment rates (t d.m. ha^{-1} yr^{-1});

$$G_{PRJ,BG,i,t} = G_{PRJ,AG,i,t} \bullet R_i \qquad\qquad (33b)$$

where R_i is the root:shoot ratio in polygon, i. R_i should ideally be estimated for each polygon, but these data are difficult to derive empirically. Hence, general relationships are acceptable (Cairns, 1997).

Equations 32 and 33 can be used directly to calculate $\Delta C_{PRJ,G,t}$ when all tree cover within a polygon is removed by harvesting (i.e., clearfelling) and no residual structure is retained. In cases of partial harvesting and/or multiple entries into a polygon, these equations must be applied separately to each of the resulting sub-polygons (the different age classes that are created). This ensures that growth rates reflect the difference in forest age between the sub-polygons.

The ex ante and ex post calculation of $G_{PRJ,i,t}$ (either directly, or from its component parts) will be derived from models that require inputs derived, in part, from forest inventory data updated from monitoring sample plots (see Sections 13.2 and 9.2). Criteria for model suitability are provided in 8.1. The exact form of the input data depends on the nature of the model but may include site index, species composition, and volume (see notes in Section 8).

9.3.2 Live Biomass Loss

The annual decrease in aboveground tree carbon from live biomass loss ($\Delta C_{PRJ,L,t}$; t C yr^{-1}) is the sum of losses from:

1. Natural mortality (i.e. insects, disease, competition, wind, etc.)
2. Commercial round wood felling
3. Incidental sources.

Losses must be specific to a given polygon; each polygon must be summed in order to calculate total annual loss across the project activity area. The live biomass losses are not emitted directly, but rather are transferred to dead organic matter pools.

$$\Delta C_{PRJ,L,t} = \Sigma(LBL_{PRJ,NATURALi,t} + LBL_{PRJ,FELLINGS,i,t} + LBL_{PRJ,OTHERi,t}) \bullet CF \qquad (34)$$

where:

$LBL_{PRJ,NATURALi,t}$ = annual loss of live tree biomass due to natural mortality in polygon, i; t d.m. yr^{-1}

$LBL_{PRJ,FELLINGS,i,t}$ = annual loss of live tree biomass due to commercial felling in polygon, i; t d.m. yr^{-1}

$LBL_{PRJ,OTHER,i,t}$ = annual loss of live tree biomass from incidental sources in polygon, i; t d.m. yr^{-1}

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

$$LBL_{PRJ,NATURALi,t} = A_{PRJ,i} \bullet LB_{PRJ,i,t} \bullet f_{PRJ,NATURAL,i,t} \qquad (35)^{23}$$

where

$A_{PRJ,i}$ = area (ha) of forest land in polygon, i;

$LB_{PRJ,i,t}$ = average live tree biomass (t d.m. ha^{-1}) in polygon, i, for year, t

$LB_{PRJ,i,t}$ is calculated for year, t, beginning with biomass estimates in year t=1 (the project start year) and with annual biomass increments ($G_{PRJ,i,t}$) added as per calculations in equation 33a.

$f_{PRJ,NATURAL,i,t}$ = the annual proportion of biomass that dies from natural mortality in forest type , i (unitless; $0 \leq f_{PRJ,NATURALi} \leq 1$), year, t. Tree mortality is an ongoing process during stand development. Trees die as a consequence of insect attack, disease, competition, or some combination thereof. Hence, mortality can be highly variable between years. This parameter can be applied uniformly across an analysis unit, or individually to a given polygon. Ex post estimates from regional data sources in corresponding stand types are preferred. Sources for mortality estimates include permanent sample plots in similar stand types, literature reports, and inventory data. Some models (the FORECAST model, for example) simulate annual background mortality rates directly and can accommodate variable age structures following partial harvesting.

$$LBL_{PRJ,FELLINGS,i,t} = A_{PRJ,i} \bullet LB_{PRJ,i,t} \bullet f_{PRJ,HARVEST,i,t} \qquad (36)$$

where:

$A_{PRJ,i}$ = area (ha) of forest land in polygon, i

$LB_{PRJ,i,t}$ = average live tree biomass (t d.m. ha^{-1}) in polygon, i, for year, t (see equation 7 for its calculation).

$f_{PRJ,HARVEST,i,t}$ = the proportion of biomass removed by harvesting from polygon, i, (unitless; $0 \leq f_{PRJ,HARVESTIi} \leq 1$), in year, t. Data for this variable should be obtained from harvest schedule information. Values may be constrained by (a) the value of $f_{PRJ,NATURAL,i,t}$ (i.e., $f_{PRJ,HARVEST,i,t} < 1-f_{PRJ,NATURAL,i,t}$), and/or (b) the area of timber available for commercial harvest.

Incidental loss ($LBL_{PRJ,OTHER,i,t}$; t d.m. yr^{-1}) is the additional live tree biomass removed for road and landing construction in the polygon, i, and is calculated as a proportion of biomass removed by harvesting:

$$LBL_{PRJ,OTHER,i,t} = A_{PRJ,i} \bullet LB_{PRJ,i,t} \bullet f_{PRJ,HARVEST,i,t} \bullet f_{PRJ,DAMAGE,i,t} \qquad (37)$$

where:

$A_{PRJ,i}$ = area (ha) of forest land in polygon, i;

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[23] Note, for Equation 35, 36, and 37: $(f_{PRJ,NATURAL,i,t} + f_{PRJ,HARVEST,i,t} + f_{PRJ,DAMAGE,i,t}) \leq 1.0$

$LB_{PRJ,i,t}$ = average live tree biomass (t d.m. ha^{-1}) in polygon, i, for year, t

$f_{PRJ,HARVEST,i,t}$ = the proportion of biomass removed by harvesting from polygon, i, in year, t (unitless; $0 \leq f_{PRJ,HARVEST,i,t} \leq 1$).

$f_{PRJ,DAMAGE,i,t}$ = the proportion of additional biomass removed for road and landing construction in polygon, i, year, t (unitless; $0 \leq f_{PRJ,DAMAGE,i,t} \leq 1$)[24]. Data for this variable should be based on regional and local comparative studies and experiential information derived from the local forest industry[25].

9.3.3 Dead Organic Matter Dynamics ($\Delta C_{PRJ,DOM}$)

Dead organic matter (DOM) included in this methodology comprises three components: standing dead wood (minimum $\geq$ 5 cm DBH and 1.3 m height; termed snags), lying dead wood (minimum $\geq$ 5 cm DBH; LDW), and belowground dead wood (i.e., dead roots). Standing dead wood is < 45º of vertical, while lying dead wood is $\geq$ 45º of vertical.

The annual change in carbon stocks in DOM ($\Delta C_{PRJ,DOM}$; t C yr^{-1}) is calculated as:

$$\Delta C_{PRJ,DOM,t} = \Delta C_{PRJ,LDW,t} + \Delta C_{PRJ,SNAG,t} + \Delta C_{PRJ,DBG,t} \qquad (38)$$

where:

$\Delta C_{PRJ,LDW,t}$ = change in lying dead wood (LDW) carbon stocks in year, t; t C yr^{-1}

$\Delta C_{PRJ,SNAG,t}$ = change in snag carbon stock in year, t; t C yr^{-1}

$\Delta C_{BSL,DBG,t}$ = change in belowground carbon stock in year, t; t C yr^{-1}.

$$\Delta C_{PRJ,LDW,t} = \Sigma(LDW_{PRJ,IN,i,t} - LDW_{PRJ,OUT,i,t}) \bullet CF \qquad (39a)$$

$$LDW_{PRJ,i,t+1} = LDW_{PRJ,i,t} + (LDW_{PRJ,IN,i,t} - LDW_{PRJ,OUT,i,t}) \qquad (39b)$$

where:

$LDW_{PRJ,i,t}$= The total mass of lying dead wood accumulated in polygon i at time t (t d.m.).

$LDW_{PRJ,IN,i,t}$ = annual increase in LDW biomass for polygon i, year, t (t d.m ha^{-1} yr^{-1}). LDW increases occur as a result of natural mortality (typically, blowdown), and as a direct or indirect result of harvesting.

$LDW_{PRJ,OUT,i,t}$ = annual loss in LDW biomass through decay, for polygon i, year, t, (t d.m ha^{-1} yr^{-1})

$LDW_{PRJ,IN,i,t}$ and $LDW_{PRJ,OUT,i,t}$ are summed across polygons.

CF = carbon fraction of dry matter (IPCC default value = 0.5).

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[24] Projecting ex ante road and landing removals beyond a few years is difficult and complex. As described, $f_{PRJ,DAMAGE,i,t}$ functions as a proxy for estimating biomass impacts of all new roads and landings associated with annual harvesting in polygon, i. Project proponents can simulate $LBL_{PRJ,OTHER,i,t}$ directly, if appropriate models are available.
[25] $f_{PRJ,DAMAGE,i,t}$ may be zero or de minimis in cases where a polygon is already roaded.

$LDW_{PRJ,IN,i,t} = (LBL_{PRJ,NATURALi,t} - LBL_{PRJ,NATURALi,t} \bullet R_i) \bullet f_{PRJ,BLOWDOWN,i,t} +$

$\qquad ((LBL_{PRJ,FELLINGS,i,t} - LBL_{PRJ,FELLINGS,i,t} \bullet R_i) +$

$\qquad (LBL_{PRJ,OTHER,i,t} - LBL_{PRJ,OTHER,i,t} \bullet R_i)) \bullet f_{PRJ,BRANCH,i,t} +$

$\qquad ((LBL_{PRJ,FELLINGS,i,t} - LBL_{PRJ,FELLINGS,i,t} \bullet R_i) +$

$\qquad (LBL_{PRJ,OTHER,i,t} - LBL_{PRJ,OTHER,i,t} \bullet R_i)) \bullet$

$\qquad (1 - f_{PRJ,BRANCH,i,t}) \bullet f_{PRJ,BUCKINGLOSS,i,t} + SNAG_{PRJ,,i,t} \bullet f_{PRJ,SNAGFALLDOWN,i,t}$ (40)

where:

$LBL_{PRJ,NATURALi,t}$, $LBL_{PRJ,FELLINGS,i,t}$, and $LBL_{PRJ,OTHER,i,t}$ are as calculated in equations 35, 36, and 37, respectively.

R_i is the root:shoot ratio in polygon, *i* (see equation 33b).

$f_{PRJ,BLOWDOWN,i,t}$ = the annual proportion of live aboveground tree biomass subject to blowdown in polygon, *i,* year*, t* (unitless; $0 \leq f_{PRJ,BLOWDOWN,i,t} \leq 1$). Ex ante estimates shall be derived preferably from regional reports in similar forest types.

$f_{PRJ,BRANCH,i,t}$ = the annual proportion of aboveground tree biomass comprised of branches $\geq$ 5 cm diameter in polygon, *i* (unitless; $0 \leq f_{PRJ,BRANCH,i,t} \leq 1$). Ex ante data are available from allometric equations and models (for example, (Kurz & Apps, 2006) for Canada; (Smith, Miles, Vissage, & Pugh, 2004) for the U.S.). In the event slash burning is undertaken, this parameter should be reduced accordingly to reflect the proportion of biomass remaining. Estimates should be obtained from expert opinion; as a default, assume 100% consumption.

$f_{PRJ,BUCKINGLOSS,i,t}$ = the annual proportion of the log bole biomass left on site after assessing and/or merchandizing the log bole for quality, in polygon, *i* (unitless; $0 \leq f_{PRJ,BUCKINGLOSS,i,t} \leq 1$). Preferably, data for this variable shall be based on regional and local comparative studies and experiential information derived from the local forest industry. Otherwise, an average default value of 21% can be used, based on US national summary statistics(Smith, Miles, Vissage, & Pugh, 2004).

$SNAG_{PRJ,i,t}$ = the total mass of the snag pool in polygon, *i*, year, *t* (see equation 42b).

$f_{PRJ,SNAGFALLDOWN,i,t}$ = the annual proportion of snag biomass in polygon, *i*, year, *t*, that falls over and thus is transferred to the LDW pool (unitless; $0 \leq f_{PRJ,SNAGFALLDOWN,i,t} \leq 1$). Ex ante estimates for this parameter can be derived from peer reviewed literature (for example, (Parish, Antos, Ott, & Di Lucca, 2010) and forest carbon accounting models that track the rates of input and losses from dead organic matter pools (for example, (Kurz & et al, 2009).

$LDW_{PRJ,OUT,i,t} = LDW_{PRJ,i,t} \bullet f_{PRJ,lwDECAY,i,t}$ (41)

where:

$LDW_{PRJ,i,t}$ = the total amount of lying deadwood mass in polygon *i*, year*, t (see equation 39b)*.
$f_{PRJ,lwDECAY,i,t}$ = the annual proportional loss of lying dead biomass due to decay, in polygon *i,*

year, t (unitless; ; $0 \leq f_{PRJ,lwDECAY,i,t} \leq 1$). A common approach to ex ante estimation of $f_{PRJ,lwDECAY,i,t}$ is to assume mass loss occurs in proportion to the amount of mass remaining in accordance with an a single exponential model, of the general form:

$$Y_t = Y_o \, e^{-kt}$$

where Y_o is the initial quantity of material, Y_t the amount left at time t, and k is a decay constant (Harmon, et al., 1986). Other types of exponential models are available (reviewed in (Harmon, et al., 1986)) and may be more appropriate to particular forest types (to be described and justified by the project proponent, if used). Ex ante estimates for the decay parameter appropriate for the project should be derived from peer-reviewed literature (for example, (Harmon, et al., 1986); (Laiho & and Prescott, 2004); (Harmon et al, 2008)).

The change in standing dead wood (snag) carbon stock in year, t (t C yr^{-1}) is calculated as:

$$\Delta C_{PRJ,SNAG,t} = \Sigma(SNAG_{PRJ,IN,i,t} - SNAG_{PRJ,OUT,i,t}) \bullet CF \qquad (42a)$$

$$SNAG_{PRJ,i,t+1} = SNAG_{PRJ,i,t} + (SNAG_{PRJ,IN,i,t} - SNAG_{PRJ,OUT,i,t}) \qquad (42b)$$

where:

$SNAG_{PRJ,i,t}$ = The total mass of snags accumulated in polygon i at time t (t d.m.)

$SNAG_{PRJ,IN,i,t}$ = annual gain in snag biomass for polygon i, year, t (t d.m ha^{-1} yr^{-1}). Snag biomass develops as a result of natural mortality. In cases where snags are created through management activities, these should be accounted for here.

$SNAG_{PRJ,OUT,i,t}$ = annual loss in snag biomass through decay, or falldown (i.e, transfer to the LDW pool)(t d.m ha^{-1} yr^{-1})

CF = carbon fraction of dry matter (IPCC default value = 0.5).

Note that $SNAG_{PRJ,IN,i,t}$ and $SNAG_{PRJ,OUT,i,t}$ are summed across polygons.

$$SNAG_{PRJ,IN,i,t} = (LBL_{PRJ,NATURALi,t} - LBL_{PRJ,NATURALi,t} \bullet R_i) \bullet (1 - f_{PRJ,BLOWDOWN,i,t}) \qquad (43)$$

where:

$LBL_{PRJ,NATURALi,t}$ is as calculated in equation 35, and

$1 - f_{PRJ,BLOWDOWN,i,t}$ is the proportion of live tree aboveground biomass that dies in polygon, i, year, t, but remains as standing dead organic matter (i.e. snags) (unitless; $0 \leq f_{PRJ,BLOWDOWN,i,t} \leq 1$). Ex ante default estimates for this calculation can be derived from literature values (for example (Harmon, et al., 1986); (Runkle, 2000); (Harmon et al, 2008)) and should be matched to the ecosystems that most closely characterize the project area.

$$SNAG_{PRJ,OUT,i,t} = SNAG_{PRJ,i,t} \bullet f_{PRJ,SWDECAY,i,t} + SNAG_{PRJ,i,t} \bullet f_{PRJ,SNAGFALLDOWN,i,t} \qquad (44)$$

where:

$SNAG_{PRJ,i,t}$ = the total amount of snag mass in polygon i, year, t (see equation 42b). $f_{PRJ,SWDECAY,i,t}$ = the annual proportional loss of snag biomass due to decay, in polygon, i, year, t (unitless; $0 \leq f_{PRJ,SWDECAY,i,t} \leq 1$). As with lying dead wood, a common approach to estimating $f_{PRJ,SWDECAY,i,t}$ is to assume mass loss occurs in proportion to the amount of mass remaining in accordance with an a single exponential model (see equation 41). Ex ante estimates for this parameter can be derived from peer reviewed literature appropriate for the project site (for example, Vanderwel et al. 2006a) and forest carbon accounting models that track the rates of input and losses from dead organic matter pools for each forest type, productivity, and age-class (see, for example, Vanderwel et al., 2006b; (Kurz & et al, 2009)).

$f_{PRJ,SNAGFALLDOWN,i,t}$ = the annual proportion of snag biomass in polygon, i, that falls over and thus is transferred to the LDW pool (unitless; $0 \leq f_{PRJ,SNAGFALLDOWN,i,t} \leq 1$). See equation 40 for parameter estimates.

The annual change in DOM derived from dead belowground biomass ($\Delta C_{PRJ,DBG,,t}$; t C yr^{-1}) is calculated for each polygon as per equation 45a. Calculation of $\Delta C_{PRJ,DBG,t}$ is specific to a given polygon; each polygon must therefore be summed in order to calculate total annual loss across the project activity area.

$$\Delta C_{PRJ,DBG,t} = \Sigma(DBG_{PRJ,IN,i,t} - DBG_{PRJ,OUT,i,t}) \bullet CF \qquad (45a)$$

$$DBG_{PRJ,i,t+1} = DBG_{PRJ,i,t} + (DBG_{PRJ,IN,i,t} - DBG_{PRJ,OUT,i,t}) \qquad (45b)$$

where:

$DGB_{PRJ,i,t}$ = The total quantity of dead belowground biomass accumulated in polygon i at time t (t d.m.).

$DBG_{PRJ,IN,i,t}$ = annual gain in dead belowground biomass for polygon i, year, t (t d.m ha^{-1} yr^{-1}). Dead belowground biomass develops as a result of mortality through natural causes or through harvesting activities.

$DBG_{PRJ,OUT,i,t}$ = annual loss in dead belowground biomass through decay, (t d.m ha^{-1} yr^{-1})

CF = carbon fraction of dry matter (IPCC default value = 0.5).

$$DBG_{PRJ,IN,i,t} = [(A_{PRJ,i} \bullet LB_{PRJ,i,t} \bullet R_i) \bullet (f_{PRJ,NATURAL,i,t} + f_{PRJ,HARVEST,i,t} + f_{PRJ,DAMAGE,i,t})] \qquad (45c)$$

where:

$A_{PRJ,i}$ = area (ha) of forest land in polygon, i;

$LB_{PRJ,i,t}$ = average live tree biomass (t d.m. ha^{-1}) in polygon, i, for year, t. $LB_{PRJ,i,t}$ is calculated for year, t, beginning with biomass estimates in year t=1 (the project start year) and with annual biomass increments ($G_{PRJ,i,t}$) added as per calculations in equation 33 a, b. This value is then multiplied by $A_{PRJ,i}$, the area (ha) of forest land in polygon, i.

R_i is the root:shoot ratio in polygon, i (see equation 33b).

$f_{PRJ,NATURAL,i,t}$ = the annual proportion of biomass that dies from natural mortality in polygon, i (unitless; $0 \leq f_{NATURALi} \leq 1$), year, t (see equation 35),

$f_{PRJ,HARVEST,i,t}$ = the proportion of biomass removed by harvesting from polygon, *i*, (unitless; $0 \leq f_{PRJ,HARVESTli} \leq 1$), year, *t* (see equation 36),

$f_{PRJ,DAMAGE,i,t}$ = the proportion of additional biomass removed by for road and landing construction in polygon, *i* (unitless; $0 \leq f_{PRJ,DAMAGE,i,t} \leq 1$), year, *t* (see equation 37),

$$DBG_{PRJ,OUT,i,t} = DBG_{PRJ,i,t} \bullet f_{PRJ,dgbDECAY,i,t} \qquad (45d)$$

where:

$DBG_{PRJ,i,t}$ = the total quantity of dead belowground in polygon *i*, year, *t (equation 17b).*
$f_{PRJ,dgbDECAY,i,t}$ = the annual proportional loss of dead belowground biomass due to decay, in polygon *i*, year, *t* (unitless; $0 \leq f_{PRJ,lwDECAY,i,t} \leq 1$). The ex ante estimation of the decay of dead belowground biomass should be done using a similar single exponent decay function as that described above for lying deadwood biomass. Estimates for the decay parameter appropriate for specific project should be derived from peer-reviewed literature (see for example: (Moore, Trofymow, Siltanen, Prescott, & CIDET, 2005); (Melin, Petersson, & Nordfjell, 2009).

9.4 Harvested Wood Products

See Section 8.4 for various discussion and background on HWP calculations.

The annual change in the carbon stored in harvested wood products (HWP), $\Delta C_{PRJ,HWP,t}$, is calculated as:

$$\Delta C_{PRJ,HWP,t} = \Delta C_{PRJ,PERMHWP1,t} + \Delta C_{PRJ,PERMHWP2,t} - \Delta C_{PRJ,EMITFOSSIL,t} \qquad (46)$$

$\Delta C_{PRJ,PERMHWP1,t}$ = the annual harvested carbon that remains in permanent storage after conversion to wood products during primary processing (t C yr^{-1})

$\Delta C_{PRJ,PERMHWP2,t}$ = carbon that remains in permanent storage after accounting for secondary processing of the residue carbon (biomass) generated from primary processing (t C yr^{-1})

$\Delta C_{PRJ,EMITFOSSIL,t}$ = fossil fuel emissions from harvesting (logging and log transport) and processing of the various wood products.

9.4.1 Permanent carbon storage from primary processing ($\Delta C_{PRJ,PERMHWP1,t}$)

If harvesting is occurring in the project case, see Section 8.3 for a discussion of key issues.

$$\Delta C_{PRJ,PERMHWP1,t} = \Sigma[(LBL_{PRJ,FELLINGS,i,t} - LBL_{PRJ,FELLINGS,i,t} \bullet R_l + LBL_{PRJ,OTHER,i,t} -$$
$$LBL_{PRJ,OTHER,i,t} \bullet R_l \bullet (1 - f_{PRJ,BRANCH,i,t}) \bullet (1 - f_{PRJBUCKINGLOSS,i,t})] \bullet$$
$$\Sigma(RE_{PRJk} \bullet f_{PRJ,PERMHWPk}) \bullet CF \qquad (47)$$
where:

$LBL_{PRJ,FELLINGS,i,t}$ = annual removal of aboveground live tree biomass due to commercial felling in polygon, *i*; t d.m. yr^{-1} (equation 36)

$LBL_{PRJ,OTHER,i,t}$ = annual removal of live tree biomass from incidental sources in polygon, *i*; t d.m. yr^{-1} (equation 37)

$1 - f_{PRJ,BRANCH,i,t}$ = the proportion of aboveground live tree biomass remaining after netting out branch biomass, in polygon i (unitless; $0 \leq f_{PRJ,BRANCH,i,t} \leq 1$)(see equation 40)

$1 - f_{PRJ,BUCKINGLOSS,i,t}$ = the proportion of the log bole remaining after processing for quality, in polygon, i (unitless; $0 \leq f_{PRJ,BUCKINGLOSS,i,t} \leq 1$) (equation 40)

$RE_{PRJ,k}$ = the recovery efficiency for each product type, k (unitless; $0 \leq RE_{PRJ,k} < 1$).

CF = carbon fraction of dry matter (IPCC default value = 0.5).

$$RE_{PRJ,k} = f_{PRJ,PRODUCTk} \bullet f_{PRJ,PROCESSk} \hspace{5cm} (48)$$

where:

$f_{PRJ,PRODUCTk}$ and $f_{PRJ,PROCESSk}$ = the respective fractions allocated to a given forest product type, k, and its associated processing efficiency (unitless; $0 \leq f_{PRJ,PRODUCTk}, f_{PRJ,PROCESSk} < 1$).

Bucking loss, product allocation, and primary processing efficiency estimates are project specific and may be derived from local or regional average harvesting operations and wood processing facilities when available. Alternatively, project proponents shall select local or regionally appropriate primary processing efficiencies for milling based on published data. One source of information is the CAR Forestry Protocol 3.2, Appendix C (Climate Action Reserve, 2010); national and regional published sources are also available (see for example, (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005), (Smith, Miles, Vissage, & Pugh, 2004), and references therein).

$f_{PRJ,PERMHWPk}$ = the fraction of biomass allocated to permanent storage after a 100-year time period, for each product type, k (unitless; $0 \leq f_{PRJ,PERMHWPk} < 1$). The simplest (i.e. default) approach is to use a first order decay function, of the following form (Miner, 2006):

$$f_{PRJ,PERMHWPk} = (1 / (1 + (Ln(2) / HL_k))) \wedge Y \hspace{4cm} (49)$$

where:

HL_k = the half-life of a given product type, k (years), and Y is the elapsed time (i.e, 100 years). A number of other more complex decay functions are available (reviewed in (Miner, 2006)). Selection of any particular function other than the default should be justified in the PD. If a first order function is employed, use (IPCC, 2003a) for default values (see Table 3) unless national or sub-national values are available.

9.4.2 Secondary processing of the residue carbon (biomass) generated from primary processing ($\Delta C_{PRJ,PERMHWP2,t}$)

See Section 8 for further discussion on residual manufacturing waste

The total residual biomass remaining in year t after primary product processing ($B_{PRJ,RESIDUAl,t}$; t d.m. yr^{-1}) is:

$$B_{PRJRESIDUAl,t} = \Sigma[(LBL_{PRJ,FELLINGS,i,t} - LBL_{PRJ,FELLINGS,i,t} \bullet R_i + LBL_{PRJ,OTHER,i,t} -$$

$$LBL_{PRJ,OTHER,i,t} \bullet R_i) \bullet (1 - f_{PRJ,BRANCH,i,t}) \bullet (1 - f_{PRJ,BUCKINGLOSS,i,t})] \bullet$$

$$\Sigma(f_{PRJ,PRODUCTk} - RE_{PRJ,k}) \tag{50}$$

where:

$RE_{PRJ,k}$ is as defined in equation 48; all other terms are defined in equation 47.

For purposes of secondary manufacturing, it is assumed that any residual biomass derived from paper production (i.e., black liquor) is combusted at 100% efficiency (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005), a conservative assumption. Hence, the final summation term in $B_{PRJ,RESIDUAl,t}$ is therefore calculated for all product types, except paper.

Let $f_{PRJ,BARK}$, $f_{PRJ,COARSE}$, and $f_{PRJ,FINE}$, be the proportions of bark, coarse, and fine residual biomass, respectively, (unitless; $0 \leq f_{PRJ,BARKt}$, $f_{PRJ,COARSEt}$, $f_{PRJ,FINEt} < 1$) that comprise $B_{PRJ,RESIDUAl,t}$. In addition, let $f_{PRJ,BARKUSE}$, $f_{PRJ,COARSEUSE}$, and $f_{PRJ,FINEUSE}$ be the proportions of each of these biomass categories that are allocated to secondary manufacturing (unitless; $0 \leq f_{PRJ,BARKUSE}$, $f_{PRJ,COARSEUSE}$, $f_{PRJ,FINEUSE} < 1$).

The biomass allocated to secondary processing of bark, and coarse and fine residuals, in year, t (t d.m. yr^{-1}), is therefore:

$$B_{PRJ,BARK,t} = B_{PRJ,RESIDUAl,t} \bullet f_{PRJ,BARK} \bullet f_{PRJ,BARKUSE} \tag{51a}$$

$$B_{PRJ,COARSE,t} = B_{PRJ,RESIDUAl,t} \bullet f_{PRJ,COARSE} \bullet f_{PRJ,COARSEUSE} \tag{51b}$$

$$B_{PRJ,FINE,t} = B_{PRJ,RESIDUAl,t} \bullet f_{PRJ,FINE} \bullet f_{PRJ,FINEUSE} \tag{51c}$$

Default values are 26.5%, 42.9%, and 30.6%, for $f_{PRJ,BARK}$, $f_{PRJ,COARSE}$, and $f_{PRJ,FINE}$, respectively (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005). Default values are 85%, and 42%, for $f_{PRJ,COARSEUSE}$, and $f_{PRJ,FINEUSE}$, respectively (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005)). Evidence indicates that on average 80% of bark is combusted for energy, with the remainder used principally as mulch (Perlack et al. 2005). Decay rates for mulch are difficult to estimate. Hence, as a default, all bark is assumed to be 100% combusted, a conservative assumption. Local data should be used for all variables, if available.

$B_{PRJ,COARSE,t}$ and $B_{PRJ,FINE,t}$ must now be allocated to particular product classes in order to derive estimates of permanence from secondary manufacturing using the 100-year method ($\Delta C_{PRJ,PERMHWP2,t}$).

$$\Delta C_{PRJ,PERMHWP2,t} = B_{PRJ,COARSE,t} \bullet f_{PRJ,PROCESSc} \bullet f_{PRJ,PERMHWPc} + B_{PRJ,FINE,t} \bullet f_{PRJ,PROCESSf}$$

$$\bullet f_{PRJ,PERMHWPf} \tag{52}$$

Processing efficiencies ($f_{PRJ,PROCESSc}$ and $f_{PRJ,PROCESSf}$) in secondary manufacturing are typically much higher than primary manufacturing. Hence, a default value of 85% can be used (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005). With respect to calculating permanent storage, the default approach is to assume that $B_{PRJ,COARSE,t}$ has a half-life equivalent to sawnwood, and $B_{PRJ,FINE,t}$ has a half-life equivalent to non-structural panels (see Table 4). These values are then used in equation 20 to calculate the fraction of biomass allocated to permanent storage after a 100-year time period, for the coarse and fine material. Alternative half-lives (see (Miner, 2006)) can be used if justified from industry-specific information.

9.5 Fossil fuel emissions associated with logging, transport, and manufacture

Annual fossil fuel emissions from harvesting and processing of the various wood products ($C_{PRJ,EMITDIRECT,t}$) are calculated as:

$$C_{PRJ,EMITFOSSIL,t} = \Delta C_{PRJ,EMITHARVEST,t} + \Delta C_{PRJ,EMITMANUFACTURE,t} + \Delta C_{PRJ,EMITTRANSPORT,t} \qquad (53)$$

Where

$\Delta C_{PRJ,EMITHARVEST,t}$ = the annual fossil fuel emissions associated with harvesting of raw material (t C yr^{-1})

$\Delta C_{PRJ,EMITMANUFACTURE,t}$ = the annual fossil fuel emissions associated with the manufacturing of raw material (t C yr^{-1})

$\Delta C_{PRJ,EMITTRANSPORT,t}$ = the annual fossil fuel emissions associated with the transport of raw material (t C yr^{-1})

The simplest approach to calculating $C_{PRJ,EMITFOSSIL,t}$ is to use published or derived carbon emission intensity factors. In the case of harvesting, $\Delta_{PRJ}C_{EMITHARVEST,t}$; t C yr^{-1}), can be calculated as:

$$\Delta C_{PRJ,EMITHARVEST,t} = \Sigma[(LBL_{PRJ,FELLINGS,i,t} - LBL_{PRJ,FELLINGS,i,t} \bullet R_i + LBL_{PRJ,OTHER,i,t} -$$

$$LBL_{PRJ,OTHER,i,t} \bullet R_i) \bullet (1 - f_{PRJ,BRANCH,i,t}) \bullet (1 - f_{PRJ,BUCKINGLOSS,i,t})] \bullet$$

$$CF \bullet c_{HARVEST} \qquad (54a)$$

where:

$c_{HARVEST}$ = carbon emission intensity factor (t C emitted/t C raw material) associated with harvesting (see Table 4 for default values); all other terms are as defined in equation 19.

$\Delta C_{PRJ,EMITTRANSPORT,t}$ must be calculated after consideration of the transport distance from harvest to processing facility, and the means of transportation. This term can be calculated as follows (after (Heath, et al., 2010)):

$$\Delta C_{PRJ,EMITTRANSPORT,t} = \Sigma[(LBL_{PRJ,FELLINGS,i,t} - LBL_{PRJ,FELLINGS,i,t} \bullet R_i + LBL_{PRJ,OTHER,i,t} -$$

$$LBL_{PRJ,OTHER,i,t} \bullet R_i) \bullet (1 - f_{PRJ,BRANCH,i,t}) \bullet (1 - f_{PRJ,BUCKINGLOSS,i,t})] \bullet$$

$$CF \bullet \Sigma(f_{PRJ,TRANSPORTk} \bullet d_{TRANSPORTk} \bullet c_{TRANSPORTk}) \qquad (54b)$$

where:

$f_{PRJ,TRANSPORTk}$ = the fraction of raw material transported by transportation type, k. (unitless; $0 \leq f_{PRJ,TRANSPORTk} < 1$).

$d_{TRANSPORTk}$ = the distance transported by transportation type, k. (km);

$c_{TRANSPORTk}$ = the carbon emission intensity factor (kg C emitted/t C raw material) associated with transportation type, k (see Table 4 for default values); all other terms are as defined in equation 19.

$$\Delta C_{PRJ,EMITMANUFACTURE,t} = \Sigma[(LBL_{PRJ,FELLINGS,i,t} - LBL_{PRJ,FELLINGS,i,t} \bullet R_i + LBL_{PRJ,OTHER,i,t} -$$

$$LBL_{PRJ,OTHER,i,t} \bullet R_i) \bullet (1 - f_{PRJ,BRANCH,i,t}) \bullet (1 - f_{PRJ,BUCKINGLOSS,i,t})] \bullet$$

$$\Sigma(f_{PRJ,PRODUCTk} \bullet c_{MANUFACTUREk}) \bullet CF \qquad\qquad (55)$$

$c_{MANUFACTUREk}$ = the carbon emission intensity factor (t C emitted/t C raw material) associated with manufacture of product type, k; all other terms are as defined in equation 19.

Default values for $c_{MANUFACTUREk}$ are provided in Table 4. Data are from a comprehensive analysis conducted in Finland (Pingoud, Perälä, Soimakallio, & Pussinen, 2003). Higher comparative values from North America are provided for harvesting and sawnwood manufacturing to illustrate inherent variability. Project proponents may use the default values in Table 4, or substitute regional data, if available.

10 Leakage

Leakage is defined as any increase in GHG emissions that occurs outside the project boundary (but within the same country), and is measurable and attributable to the project activities. All leakage shall be assessed and accounted for in GHG calculations. Positive leakage effects must be discounted.

10.1 Activity Shifting Leakage:

Activity shifting leakage occurs when the actual agent of harvesting moves to an area outside of the project boundary and initiates compensatory harvesting activities elsewhere. Activity shifting leakage in IFM projects can result from current activities shifting within the project proponent's operations due to the implementation of the carbon project. This effectively offsets a portion of the benefits of the carbon project emissions reductions. The project proponent will demonstrate that, as per VCS requirements for IFM projects and the applicability conditions of this methodology, there is no leakage due to activity shifting within the project proponents' lands upon the start up of the project[26], using the following steps:

STEP 1 - The project proponent shall annually provide to the validator and/or verifier the locations and descriptions of all forestlands within the project country over which the project proponent has ownership, management, or legally sanctioned rights of use.

STEP 2 - Project proponents shall demonstrate annually that there is no activity shifting leakage to areas that are outside the project area but within the project proponents operating areas, and that the management plans and/or land-use designations of all other lands operated by the project proponent have not materially changed as a result of the project activity (e.g., harvest rates have not been increased). Demonstration methods will include:

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[26] See footnote 4 (and applicability criterion 7) for further requirements in the event activity shifting is found to be occurring in later years of the project duration.

1. Historical records showing trends in harvest volumes paired with records from the project time period showing no deviation from historical trends, or
2. Forest management plans prepared ≥ 24 months prior to the start of the project showing harvest plans on all owned/managed lands paired with records from the project time period showing no deviation from management plans.

Additional evidence and justification may be utilized to demonstrate activity shifting related to the project is not occurring.

10.2 Market Leakage:

Market leakage risk occurs when a project significantly reduces the production of a commodity causing a change in the supply and market demand equilibrium that results in a shift of production elsewhere to make up for the lost supply. VCS provides project proponents with two options for quantifying market leakage, which are further defined for this methodology:

1. Apply the most current VCS market leakage tool to determine a discount factor to the net change in carbon stock associated with the activity that reduces timber harvest (see Section 10.2.1); or,
2. Develop a project-specific market leakage factor that accounts for country level leakage within similar forest types[27]. This methodology allows two variations on this option:
   a. Utilize the CAR Forest Protocol 3.2 market leakage equation, if the project is located within countries where CAR applies, or can demonstrate equivalent market conditions (currently CAR applies only in the US but is developing protocol assumptions for Mexico and Canada) (see Section 10.2.2); or
   b. Utilize a detailed leakage risk assessment form provided in this methodology and provide related additional supporting evidence for the assessments made therein (see Section 10.2.3).

10.2.1 Market Leakage Option 1 – VCS Default Market Leakage Discount Factors

In exercising this option, project proponents shall utilize the most current approved VCS leakage discount method as outlined in the most recent VCS AFOLU requirements document[28]. Projects will determine the appropriate discount factor in accordance with the most recent requirements for market leakage. Project proponents shall provide justification and evidence of how the leakage discount factor is determined.

For project proponents using Market Leakage Option 1:

The outcome of the VCS Leakage Discount Factor determination = the value for MLF$_y$ (56a)

To calculate the project market leakage (LE$_Y$, t CO2e yr^{-1}):

LE$_Y$ = MLF$_y$ • ER$_{y,GROSS}$ **(56b)**

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[27] Specifically: "…market leakage shall be accounted for at the country-scale applied to the same general forest type as the project (i.e., forests containing the same commercial species as the forest in the project area)…." (Voluntary Carbon Standard, 2008b).
[28] Note the VCS May 24th AFOLU Program Update, which specifies using the ratio of merchantable biomass to total biomass in the project versus leakage area.

Where,

MLF_y = Market leakage factor, as calculated above.

$ER_{y,GROSS}$ = the gross difference in the overall annual carbon change between the baseline and project scenarios in year 'y' (in tonnes CO_2e yr^{-1}). This term is calculated in equation 57.

10.2.2   Market Leakage Option 2 – CAR Market Leakage Formula

Based on the fact that the CAR forest protocol is widely accepted in North America, thoroughly reviewed, generally mutually recognized by VCS, and developed for a single country leakage condition; it is considered a valid approach to leakage discount factors when applied to projects located in CAR-eligible jurisdictions (currently the United States). Further, project proponents may justify the application of the CAR leakage formula for log market conditions fundamentally similar to the United States and which are currently under development as CAR jurisdictions (i.e. Canada and Mexico pending).

The CAR leakage formula is calculated as per the latest approved CAR Forest Protocol. The currently approved calculation is provided Figure 1, which is to be replaced by the most up to date approved CAR method as required:

Figure 1 - CAR Forestry Protocol v.3.2 Market Leakage Process[29][30]

Forest Project Protocol   *Version 3.2, August 2010*

6.2.6 Quantifying Secondary Effects

For Improved Forest Management Projects, significant Secondary Effects can occur if a project reduces harvesting in the Project Area, resulting in an increase in harvesting on other properties. Changes in energy-related emissions, which could result from a Forest Project causing consumers of forest products to increase or decrease their use of alternative materials, are not accounted for because it is assumed that energy sector emissions will be capped in the relatively near future under a regulatory cap-and-trade system.

Equation 6.10 must be used to estimate Secondary Effects for Improved Forest Management Projects.

Equation 6.10. Secondary Effects Emissions

$$If \sum_{n=1}^{y-1}(AC_{hv,n} - BC_{hv,n}) > 0, then \ SE_y = 0$$

$$If \sum_{n=1}^{y-1}(AC_{hv,n} - BC_{hv,n}) < 0, then \ SE_y = (AC_{hv,y} - BC_{hv,y}) \times 20\%$$

Where,

SE_y	=	Estimated annual Secondary Effects (used in Equation 6.1)
$AC_{hv,\,n}$	=	Actual amount of onsite carbon harvested in reporting period n (prior to delivery to a mill), expressed in CO_2-equivalent tonnes
$BC_{hv,\,n}$	=	Estimated average baseline amount of onsite carbon harvested in reporting period n (prior to delivery to a mill), expressed in CO_2-equivalent tonnes, as determined in Step 1 of Section 6.2.3
y	=	The current year or reporting period

For project proponents using Leakage Option 2:

Utilize the CAR formulas (Equation 6.10 – shown in Figure 1), with variables calculated as follows:

Note: for consistency, y = n = t.

$BC_{hv,\,n} = \Sigma[$ (LBL$_{BSL,FELLINGS,i,t}$ - LBL$_{BSL,FELLINGS,i,t}$ • R$_i$ + LBL$_{BSL,OTHER,i,t}$ -

          LBL$_{BSL,Other,i,t}$ • R$_i$) • (1 - f$_{BSL,BRANCH,i,t}$) • (1 - f$_{BSL,BUCKINGLOSS,i,t}$)] •

           CF • 44/12   (56c.1)

As calculated using the *baseline scenario data*, and where:

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[29] "Secondary Effects" = Market Leakage
[30] Figure 1 is to be replaced with the latest approved CAR Forest Protocol Secondary Effects calculations at the time of PD validation.

$LBL_{BSL,FELLINGS,i,t}$ = annual removal of live tree biomass due to commercial felling in polygon, i; t d.m. yr^{-1} (equation 6)

$LBL_{BSL,OTHER,i,t}$ = annual removal of live tree biomass from incidental sources in polygon, i; t d.m. yr^{-1} (equation 6)

$1 - f_{BSL,BRANCH,i,t}$ = the proportion of aboveground live tree biomass remaining after netting out branch biomass, in polygon i (unitless; $0 \leq f_{BRANCH,i,t} \leq 1$)(see equation 12)

$1 - f_{BSL,BUCKINGLOSS,i,t}$ = the proportion of the log bole remaining after processing for quality, in polygon, i (unitless; $0 \leq f_{BUCKINGLOSS,i,t} \leq 1$) (equation 12)

R_i = the root:shoot ratio in polygon, i

CF = carbon fraction of dry matter (IPCC default value = 0.5).

$$AC_{hv,n} = \Sigma[(LBL_{PRJ,FELLINGS,i,t} - LBL_{PRJ,FELLINGS,i,t} \bullet R_i + LBL_{PRJ,OTHER,i,t} -$$

$$LBL_{PRJ,Other,i,t} \bullet R_i) \bullet (1 - f_{PRJ,BRANCH,i,t}) \bullet (1 - f_{PRJ,BUCKINGLOSS,i,t})] \bullet$$

$$CF \bullet 44/12 \qquad\qquad (56c.2)$$

As calculated using the *project scenario data*, and where:

$LBL_{PRJ,FELLINGS,i,t}$ = annual removal of live tree biomass due to restoration felling in polygon, i; t d.m. yr^{-1} (equation 6)

$LBL_{PRJ,OTHER,i,t}$ = annual removal of live tree biomass from incidental sources in polygon, i; t d.m. yr^{-1} (equation 6)

$1 - f_{PRJ,BRANCH,i,t}$ = the proportion of aboveground live tree biomass remaining after netting out branch biomass, in polygon i (unitless; $0 \leq f_{BRANCH,i,t} \leq 1$)(see equation 12)

$1 - f_{PRJ,BUCKINGLOSS,i,t}$ = the proportion of the log bole remaining after processing for quality, in polygon, i (unitless; $0 \leq f_{BUCKINGLOSS,i,t} \leq 1$) (equation 12)

CF = carbon fraction of dry matter (IPCC default value = 0.5).

$$SE_y = LE_y \qquad\qquad (56c.3)$$

where:

SE_y = Secondary Effects in year 'y' (tCO_2e) calculated using equations in Figure 1 and equations 56c.1, 56c.2 and 56c.3.

LE_Y = Leakage in year y (in tonnes CO_2e yr^{-1}) – used in equation 58.

10.2.3 Market Leakage Option 3 – Leakage Assessment Tool

The VCS method for assessing leakage, based on the 2008 VCS method for calculating leakage (Voluntary Carbon Standard, 2008a), does not provide a mechanism for weighting leakage into different biomass areas, and also does not provide a mechanism to separate domestic versus international leakage proportions. This methodology therefore provides a third option to project

proponents who wish to undertake an assessment of market leakage conditions more detailed and specific to their project location and condition.

This tool sets out a procedure to weight the VCS leakage categories according to publically available forest products market data for where the leakage risk is most likely to be leaked to (or replaced from).

Following Table 5, the project proponent shall conduct the risk analysis as follows:

1. Determine the proportion of leakage expected to be replaced by international sources (i.e. proportion of international leakage) versus domestic sources, and;
2. For the domestic proportion, determine the proportion of leakage to other national biomass forests, based on the VCS default values and categories, and the ratio of merchantable biomass to total biomass on the project site versus the leakage sites.

Where a project is unable to provide any relevant published justification or supporting evidence for a risk factor selection in Table 5, then the project is not eligible to use this tool and must use one of the other provided options to assess market leakage risk.

Table 5 - Market Leakage Option 3 Assessment Table

1.	International Leakage Proportion			
	In order to determine the proportion of potential leakage which will occur within domestic markets versus international markets, the project proponent must calculate the proportion of the project leakage which is expected to be _replaced from_ domestic (in-project country) sources versus the proportion that will likely be _replaced from_ international source (and hence, be international leakage, which is given a leakage risk of zero in VCS). It is assumed that the forest products market is efficient, and any leakage will be replaced proportionally across the project countries current national forest products market conditions. The following calculation provides a method to estimate the proportion of leakage which is domestic versus international. International Leakage Factor = $(FP_{TO\_DOMESTIC}) * (DOM.DEMAND_{FROM\_INTL}) + (FP_{TO\_EXPORT}) * (EXP.DEMAND_{FROM\_INTL})$ Where, $FP_{TO\_DOMESTIC}$ = Total project country forest products delivered to domestic markets (%) FP_{TO_EXPORT} = Total project country forest products delivered to export (international) markets (%) $DOM.DEMAND_{FROM\_INTL}$ = Proportion of total project country Forest Products to International Markets (%) $EXP.DEMAND_{FROM\_INTL}$ = Weighted sum of the proportions of key markets which are supplied from non-project country sources (%) Definitions: "Domestic" = project country "International" = sum of all non-project countries which individually represent >10% of the total project country's forest products production, and which collectively represent >80% of the total project country's forest products export production.			

"Forest Products" = the market data utilized must be demonstrated to be representative of >80% of the project harvested wood products product mix. Proponents may use forest products volume or value as long as the units are consistent and comparable across markets and used consistently within this entire tool.

"Key market(s)" = collectively must represent >80% of the project country's domestic, import, and export supply, either on a log basis or lumber basis. Individual market countries representing <10% of the total domestic or export market may be excluded.

Example:

Example of *Canadian-based* projects under this tool (Stats Can Data & FAO data) (only the US market meets the key market definition for Canadian forest products production):

$FP_{TO\_DOMESTIC}$ = 20%

FP_{TO_EXPORT} = 80% (>90% to US = single 'Key Market')

$DOM.DEMAND_{FROM\_INTL}$ = 10% (i.e. 10% of the domestic market is supplied by non-Canadian supply)

$EXP.DEMAND_{FROM\_INTL}$ = 65% (i.e. 65% of the US market is supplied by non-Canadian supply)

LF_{INTL} = ($FP_{TO\_DOMESTIC}$) * ($DOM.DEMAND_{FROM\_INTL}$) + (FP_{TO_EXPORT}) * ($EXP.DEMAND_{FROM\_INTL}$)

LF_{INTL} = (0.20 * 0.10) + (0.80 * 0.65) = 54%

Therefore, 54% of the market leakage is expected to be replaced by international sources, which is assigned a leakage factor of "0". The remaining domestic/national leakage, 46%, is then further considered in the biomass ratio calculations below.

	International Leakage Factor (LF_{INTL}*)*	LF_{INTL} = ($FP_{TO\_DOMESTIC}$) * ($DOM.DEMAND_{FROM\_INTL}$) + (FP_{TO_EXPORT}) * ($EXP.DEMAND_{FROM\_INTL}$)

2.	**Proportional Leakage by Biomass Ratio:**			
	VCS Default Biomass Ratio Categories (see: VCS 2008 May 24, 2010 Program Update) Calculated as: ((Project Biomass Ratio – Leakage Biomass Ratio) / (Project Biomass Ratio)) * 100	> 15%[31] Lower merchantable biomass to total biomass (t/ha)	+/- 15% merchantable biomass to total biomass (t/ha)	>15% Higher merchantable biomass to total biomass (t/ha)
	Starting VCS Default Leakage Factors[32]:	20%	40%	70%
1a.	2a Calculating Weighted Average Leakage Biomass Ratio: This is a typical weighted average calculation, with the objective of creating an average difference in biomass ratio between the project and the national leakage areas, weighted by the proportion of timber			

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[31] VCS does not specify a quantitative range for determining "higher", "lower" or "similar" biomass ratios, and hence a 15% factor has been selected to represent a reasonable range of biomass ratios. This factor is consistent with other approved VCS and ACR IFM methodology approaches.
[32] These factors are from the 2008 VCS leakage calculation method, and should be retained for use in this leakage tool Option 3 regardless of new VCS market leakage tool calculations.

supply coming from each leakage forest type:

- Identify national forest type (or ecotype) data where merchantable log volume biomass and total forest biomass estimates are available (i.e. from published national inventory data sources, etc.)
- Determine the biomass ratio in each national forest type (ratio of merchantable volume in biomass (t/ha) to total biomass (t/ha);
- Determine the proportion of the domestic national market that is supplied by each of the national forest types (%);
- Determine the difference between the forest type containing the project and each leakage area biomass ratio (Biomass Ratio Difference (%) = ((Project Biomass Ratio – Leakage Area Biomass Ratio) / Project Biomass Ratio) * 100);
- Select the VCS default leakage factor for each national forest type, based on the difference between the project biomass ratio and each national forest type biomass ratio (see biomass ratio categories above);
- Multiple the proportion (%) of market supplied by each leakage forest type by the VCS Default Leakage Factor from each forest type to determine the weighted average VCS Leakage Factor for biomass ratios.

Example (simplified, using 4 national forest types):

Project is located in national forest type 1 (biomass ratio = 0.65):
Forest Type 1: Biomass Ratio = 0.65; 25% of national timber inventory
Forest Type 2: Biomass Ratio = 0.75; 30% of national timber inventory
Forest Type 3: Biomass Ratio = 0.55; 25% of national timber inventory
Forest Type 4: Biomass Ratio = 0.75; 20% of national timber inventory

Biomass Ratio difference between leakage area and project area:
Forest Type 1 = (0.65 – 0.65)/0.65 = 0 = 40% VCS Leakage Factor
Forest Type 2 = (0.65 – 0.75)/0.65 = -15.4% = 20% VCS Leakage Factor
Forest Type 3 = (0.65 – 0.55)/0.65 = 15.4% = 70% VCS Leakage Factor
Forest Type 4 = (0.65 – 0.75)/0.65 = -15.4% = 20% VCS Leakage Factor

Weighted Average = (25% * 40%) + (30% * 20%) + (25% * 70%) + (20% * 20%) = 37.4%
Example Weighted Biomass Discount Factor = 37.4%

	VCS Default Leakage Discount Factor, by forest type (selected by +-15% criteria)	*20%*	*40%*	*70%*
	Proportional of Market Supplied by National Forest Type in each Leakage Discount Category (note: X + Y + Z = 100%):	*= X*	*= Y*	*= Z*
	Proportional Biomass Leakage Discount Factor (LF$_{BIOMASS}$):	$LF_{BIOMASS} = (20\% * X) + (40\% * Y) + (70\% * Z)$		
3.	MARKET LEAKAGE FACTOR (MLF$_y$):	$=(1 - LF_{INTL})^{33} * LF_{BIOMASS}$		

For project proponents utilizing Leakage Option 3, project market leakage (LE$_Y$; t CO_2e yr^{-1}) is calculated as:

$$LE_Y = MLF_y \bullet ER_{y,GROSS} \hspace{3cm} (56d)$$

_____

[33] The inverse of the international leakage factor is the portion of the market leakage related to national leakage. International leakage is given a leakage factor discount of "0" in VCS.

where,

MLF_y = the market leakage factor in year, y (as calculate per section 10.2.3)

$ER_{y,GROSS}$ = the gross difference in the overall carbon balance between the baseline and project scenarios in year, y (t CO_2e yr^{-1}). See equation 57 for its calculation.

11 Quantification of Net GHG Emission Reduction and/or Removals

The net GHG emissions and removals are calculated for each scenario following the methods outlined in Section 8 and 9.

11.1 Summary Gross Emissions Reductions and/or Removals Equation

Gross carbon emissions reductions (ER_y,gross; t CO_2e yr^{-1}) created by the carbon project are calculated annually as the difference between the baseline and project scenario net emission reductions/emissions:

$$ER_{y,GROSS} = (\Delta C_{BSL,t} - \Delta C_{PRJ,t}) \bullet 44/12 \hspace{3cm} (57)$$

where,

$\Delta C_{BSL,t}$ = total net baseline scenario emissions calculated from equation 1 (t C yr^{-1}).

$\Delta C_{PRJ,t}$ = total net project scenario emissions calculated from equation 29 (t C yr^{-1}).

44/12 = factor to convert C to CO_2e

11.2 Summary Net Emissions Reductions and/or Removals Equation

The annual *net* carbon emissions reductions is the actual net GHG removals by sinks from the project scenario minus the net GHG removals by sinks from the baseline scenario, were then calculated by applying the leakage and uncertainty discount factors (but not the VCS permanence buffer), on an annualized basis:

$$ER_y = ER_{y,GROSS} - LE_y \hspace{4cm} (58)$$

where:

ER_y = the net GHG emissions reductions and/or removals in year y (the overall annual carbon change between the baseline and project scenarios, net all discount factors except the permanence buffer) (t CO_2e yr^{-1}).

$ER_{y,GROSS}$ = the difference in the overall annual carbon change between the baseline and project scenarios (t CO_2e yr^{-1}).

LE_y = Leakage in year y (t CO_2e yr^{-1}), as calculated in equation 56b.

11.3 Calculating Verified Carbon Units (VCU's) for the Project

The number of VCU's the project available for issuance and sale in year, y (VCU$_y$; t CO$_2$e yr^{-1}), is calculated as:

$$VCU_y = ER_y \bullet (1 - ER_{y,ERR}) - BR_y \qquad\qquad (59)$$

where:

ER_y = the net GHG emissions reductions and/or removals in year (t CO$_2$e yr^{-1}), as calculated in equation 58.

$ER_{y,ERR}$ = the uncertainty factor for year, y, (calculated in Section 11.4), expressed as a proportion.

BR_y = estimated VCU-equivalent tCO$_2$e issued to the VCS Buffer Pool in year, y, calculated using the latest version of the VCS AFOLU Non-Permanence Risk Tool. BRy is calculated by multiplying the most current verified permanence risk Buffer Withholding Percentage for the project by the change in carbon stocks (difference between baseline and project scenario) for the project area as shown on p. 24 of the VCS Guidance for AFOLU Projects (Voluntary Carbon Standard, 2008a).

11.4 Calculation of an Uncertainty Factor

Estimated carbon emissions and removals arising from AFOLU activities have uncertainties associated with forest inventory, carbon stocks, biomass growth rates, modeling error, and their various expansion factors, equations and coefficients. Use of conservative estimates, peer-reviewed scientific data and analysis, and high quality inventory sampling procedures, will mitigate uncertainty, and improve accuracy as new and reliable data are acquired over time.

To be conservative, this methodology employs an over-riding project confidence deduction as a proxy for collective project uncertainty by assessing statistical uncertainty in the forest carbon inventory *and* associated modeling. The approach is based partly on CAR's "Confidence Deduction" module (Climate Action Reserve, 2010). Project proponents are required to apply this uncertainty factor to the net emission reductions claimed by the project each year based on the results of the latest ex-post inventory field data collection and modeling output.

Note that physical field plot measurement error is calculated and compared directly against a set of minimum accuracy threshold requirements, as described in Section 13.

Refer to Section 8 for guidance on the process of stratification and how *polygons* and *analysis units* are defined.

The methodology monitoring section specifies that all analysis units or polygons[34] will have representation by one or more field plots. However, due to the difficulty of determining the independence of plot data within individual homogeneous polygons (i.e. a specifically similar

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[34] If polygons are the primary stratification unit being used by the project, then each polygon shall have field plot representation. If polygons are grouped into analysis units for the project, then each analysis unit shall have field plot representation (noting that not all polygons will have plot representation within a given analysis unit).

forest type, site, and age), it will be necessary to only calculate a single carbon density *observation* for each individual polygon sampled; either through the use of a single plot within that polygon, or calculation of the mean of multiple plots within that polygon. *Throughout these calculations a plot observation, subscript i, is defined to represent the mean of all plots within a given polygon.*

The project-level uncertainty factor is calculated as follows:

Step 1 – Calculate the average percent model error (E_M) for the project based on the average area-weighted difference between measured values in monitored plot observations and model-predicted values using Equations 60a,b. In the case where analysis units have been used for stratification, the difference between the plot observation and model-predicted value (both expressed on a per hectare basis) for a given analysis unit ($y_{d,h,i}$) is weighted by the area of its associated analysis unit ($A_{PRJ,h}$) (Eq. 60a). The use of an area-weighting factor places more emphasis on analysis units that represent a relatively larger proportion of the total project area. In the case where only polygons are used in the stratification, the area weighting term (see equations 60a-c) would change to the area of the polygon ($A_{PRJ,i}$), and the subscript, h, is dropped from the $y_{d,h,i}$ term in equations 60a-e.

$$E_M = 100 \cdot \left(\sum y_{d,h,i} / \sum (A_{PRJ,h} \cdot y_{m,h,i}) \right) \qquad (60a)$$

where:

The summation is across all plot observations, *i*, and across all analysis units , *h*;

$$y_{d,h,i} = A_{PRJ,h} \cdot (y_{m,h,i} - y_{p,h,i}) \qquad (60b)$$

E_M = Mean model error for the project (%)

$y_{d,h,i}$ = the area-weighted difference between measured and predicted carbon storage in analysis unit, *h*, plot observation, *i* (t C)

$y_{m,h,i}$ = carbon storage measured in analysis unit, *h*, plot observation, *i* (t C ha^{-1})

$y_{p,h,i}$ = carbon storage predicted by model for analysis unit , *h*, plot observation, *i* (t C ha^{-1})

$A_{PRJ,h}$ = area of project analysis unit, *h* (ha)

Step 2 – Calculate the inventory error (E_I) at a 90% confidence interval expressed as a percentage of the mean area-weighted inventory estimate from the measured plots.

This methodology was designed to accommodate complex landscapes consisting of hundreds to thousands of polygons, which can be further grouped into analysis units. Inventory error is estimated based upon the difference between modeled and measured values for monitoring plots established in polygons or in polygons grouped within analysis units.

Inventory error, E_I, is estimated by first calculating the standard error of the area-weighted differences between the plot observation measurement and the associated model-predicted carbon storage (both on a per hectare basis) for analysis units or polygons. The standard error is then multiplied by the *t*-value for the 90% confidence interval. Finally E_I is expressed in

relative terms (in Equation 60c) by dividing the 90% confidence interval of the area-weighted differences between predicted and measured values in all plots by the area-weighted average of the measured values in all monitoring plots.

$$E_I = 100 \cdot [\, SE * 1.654 / ((1/N) \cdot \sum(A_{PRJ,h} \cdot y_{m,h,i}))\,] \qquad (60c)$$

where,

E_I = Inventory error for the project (%)

SE = the project level standard error of the area weighted differences between measured plot observation and predicted values of carbon storage.

N = total number of plot observations in all analysis units or polygons[35]

1.654 = the 90% confidence interval t-value

All other terms as defined in equation 60a.

$$SE = S / \sqrt{N} \qquad (60d)$$

where,

N = total number of plot observations in all analysis units or polygons (see Footnote 37)

S = the standard deviation of the area weighted differences between measured and predicted values of carbon storage across all analysis unit or polygons.

$$S = \sqrt{[\,(1/N - 1) \cdot \sum(y_{d,h,i} - \overline{ybar}_d)^2\,]} \qquad (60e)$$

where,

$\overline{ybar}_d$ = the project-level mean of the area weighted differences between measured plot observation and predicted values of carbon storage. See equation 60b for the calculation of $y_{d,h,i}$

All other terms as defined in equation 60b and 60c.

Step 3 - The total error for the project (E_P; %) is calculated by adding the model and inventory error terms, as calculated in Steps 1 and 2.

$$E_P = E_M + E_I \qquad (60f)$$

Step 4 – Compare the result of Step 3 against

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[35] For clarity, the plot observation sample size (N) is equivalent to the number of polygons sampled (for projects using either a polygon or analysis unit stratification method). As noted, a single *plot observation* is created for each polygon using the mean when there are multiple plots within a polygon. Thus, in some situations the number of actual installed plots may be higher than the number of plot observations (N).

Table 6 to determine the uncertainty factor:

Estimated Project Error, E_P (%)	Uncertainty Factor (=$ER_{Y,ERR}$)
0 – 10%	= 1.5%[36]
>10%	= 1.5% + E_P – 10%

The uncertainty factor is calculated at each verification and applied annually until the next verification.

12 Data and Parameters Not Monitored

Selection of parameter values and assumptions requires a balance between accuracy and conservativeness. Accuracy should always prevail except when alternative values are of equivalent accuracy, in which case the more conservative value is used, the more conservative being the value that provides the least over-estimation of net anthropogenic GHG removals by sinks.

Data/parameter	$A_{BSL,i}$
Data unit	Ha
Description:	Area of baseline polygon, i
Used in	Various equations from Equation #4-17.
Source of data	GPS coordinates and/or remote sensing and/or inventory records
Measurement procedures	n/a
Comments:	

Data/parameter	$\Delta C_{,t}$
Data unit	t C yr^{-1}
Description:	The annual carbon balance in the baseline or project scenario for year, t
Used in	Equation 57, labeled by baseline (BSL) and project (PRJ).
Source of data	Calculated in equation 1 (Section 8); equation 29 (Section 9). Labeled with subscript BSL and PRJ, respectively.
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{P,t}$
Data unit	t C yr^{-1}

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[36] To be conservative, the minimum uncertainty factor is set to 1.5% to account for possible uncertainty within other unmeasured assumptions used in calculations and modeling.

Description:	The annual change in carbon stocks in all pools in the baseline or project scenario across the project activity area for year, t
Used in	Calculation of $\Delta C_{,t}$
Source of data	Calculated in equation 2 (Section 8); equation 30 (Section 9)
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{LB,t}$
Data unit	t C yr^{-1}
Description:	The annual change in carbon stocks in living tree biomass (above- and belowground) for year, t
Used in	Calculation of $\Delta C_{P,t}$
Source of data	Calculated in equation 3 (Section 8); equation 31 (Section 9)
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{DOM,t}$
Data unit	t C yr^{-1}
Description:	The annual change in carbon stocks in dead organic matter for year, t
Used in	Calculation of $\Delta C_{P,t}$
Source of data	Calculated in equation 10 (Section 8); equation 38 (Section 9)
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{HWP,t}$
Data unit	t C yr^{-1}
Description:	The annual change in carbon stocks in harvested wood products for year, t
Used in	Calculation of $\Delta C_{P,t}$
Source of data	Calculated in equation 18 (Section 8); equation 46 (Section 9)
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{G,t}$

Data unit	t C yr^{-1}
Description:	The annual change in carbon stocks due to live biomass gain for year, t
Used in	Calculation of $\Delta C_{LB,t}$
Source of data	Calculated in equation 4 (Section 8); equation 32 (Section 9)
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{L,t}$
Data unit	t C yr^{-1}
Description:	The annual change in carbon stocks due to live biomass loss for year, t
Used in	Calculation of $\Delta C_{LB,t}$
Source of data	Calculated in equation 6 (Section 8); equation 34 (Section 9)
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{LDW,t}$
Data unit	t C yr^{-1}
Description:	The annual change in lying dead wood carbon stocks for year, t
Used in	Calculation of $\Delta C_{DOM,t}$
Source of data	Calculated in equations 11a, 12, 13 (Section 8); equations 39a, 40, 41 (Section 9)
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{SNAG,t}$
Data unit	t C yr^{-1}
Description:	The annual change in standing dead wood carbon stocks for year, t
Used in	Calculation of $\Delta C_{DOM,t}$
Source of data	Calculated in equations 14a, 15, 16 (Section 8); equations 42a, 43, 44 (Section 9)
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{DBG,t}$
Data unit	t C yr^{-1}
Description:	The annual change in dead belowground carbon stocks for year, t
Used in	Calculation of $\Delta C_{DOM,t}$
Source of data	Calculated in equations 17a, 17c, 17d (Section 8); equations 45a, 45c, 45d (Section 9)
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	CF
Data unit	t C t^{-1} d.m.
Description:	Carbon fraction of dry matter
Source of data	IPCC default value = 0.5, if more relevant values are not available
Measurement procedures	n/a
Comments:	

Data/parameter	R_i
Data unit	unitless
Description:	Root:shoot ratio in polygon , i
Source of data	If project-specific values have not been measured, use Cairns 1997).
Measurement procedures	n/a
Comments:	Root allocation can be vary by site productivity; relatively more biomass may be allocated to roots in poor than richer soils

Data/parameter	BEF
Data unit	unitless
Description:	Biomass expansion factors for conversion of productivity metrics to biomass

Source of data	The source of data shall be chosen with priority from higher to lower preference as follows: (a) Existing local and forest type-specific; (b) National and forest type-specific or eco-region-specific (e.g. from national GHG inventory); (c) Forest type-specific or eco-region-specific from neighboring countries with similar conditions. Sometimes (c) might be preferable to (b); (d) Globally forest type or eco-region-specific (e.g. IPCC literature: Table 3A.1.10 of GPG-LULUCF)
Measurement procedures	n/a
Comments:	BEFs are age dependent, and use of average data may result in significant errors for both young and old stands – as BEFs are usually large for young stands and quite small for old stands.

Data/parameter	$f_{BRANCH,i,t}$
Data unit	unitless
Description:	The annual proportion of aboveground tree biomass comprised of branches $\geq$ 5 cm diameter in polygon, i
Source of data	The source of data shall be chosen with priority from higher to lower preference as follows: (a) Research publications relevant to the project area; (b) National and species-specific or group of species-specific (e.g. from National GHG inventory); (c) Species-specific or group of species-specific from neighboring countries with similar conditions. Sometimes (b) may be preferable to (a); (d) Globally species-specific or group of species-specific (e.g. IPCC GPG- LULUCF).
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, same value

Data/parameter	$f_{BUCKINGLOSS,i,t}$
Data unit	unitless

Description:	Annual proportion of the log bole biomass left on site after assessing and/or merchandizing the log bole for quality, in polygon, i
Source of data	Preferably, data for this variable shall be based on regional and local comparative studies and experiential information derived from the local forest industry. Otherwise, an average default value of 21% can be used, based on US national summary statistics (Smith, Miles, Vissage, & Pugh, 2004).
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$f_{PRODUCTk}$, and $f_{PROCESSk}$
Data unit	Unitless
Description:	The respective fractions of harvested biomass allocated to a given forest product type, k, and its associated processing efficiency
Source of data	Are project specific and may be derived from local or regional average harvesting operations and wood processing facilities when available. Alternatively, project proponents shall select local or regionally appropriate processing efficiencies for milling based on published data; first from CAR Forestry Protocol 3.2, Appendix F (Climate Action Reserve, 2010) if applicable; or from other national or regional published sources (i.e. (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005), (Smith, Miles, Vissage, & Pugh, 2004).
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	HL_k
Data unit	Years
Description:	Half-life of a given product type, k
Source of data	Use IPCC (2003a) for default values (see Table 3) unless national or sub-national values are available; variable used in both baseline (BSL) and project (PRJ) scenario, same value
Measurement procedures	n/a
Comments:	Used to calculate $f_{BSL,PERMHWPk}$ = the fraction of biomass allocated to permanent storage after a 100-year time period, for each product type, k

Data/parameter	f_{BARK}, f_{COARSE}, and f_{FINE}
Data unit	Unitless
Description:	The proportions of bark, coarse, and fine residual biomass, respectively, contained in residue derived from primary manufacturing.
Source of data	Default values are 26.5%, 42.9%, and 30.7%, for f_{BARK}, f_{COARSE}, and f_{FINE}, respectively (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005).
Measurement procedures	n/a
Comments:	Variables used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$f_{BARKUSE}$, $f_{COARSEUSE}$, and $f_{FINEUSE}$
Data unit	Unitless
Description:	The proportions of each residual biomass category allocated to secondary manufacturing
Source of data	Default values are 85%, and 42%, for $f_{COARSEUSE}$, and $f_{FINEUSE}$, respectively (Smith, Miles, Vissage, & Pugh, 2004); (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005). Default value for bark is zero (based on Perlack et al. 2005).
Measurement procedures	n/a
Comments:	Variables used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$f_{TRANSPORTk}$
Data unit	(unitless; $0 \leq f_{BSL,TRANSPORTk} < 1$).
Description:	The fraction of raw material transported by transportation type, k.
Source of data	Estimated based on Heath et al. 2006 Supplementary
Measurement procedures	n/a
Comments:	Variables used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$c_{HARVEST}$
Data unit	t C emitted/t C raw material
Description:	The carbon emission intensity factor associated with harvesting
Source of data	See Table 4
Measurement procedures	n/a
Comments:	

Data/parameter	$C_{MANUFACTUREk}$
Data unit	t C emitted/t C raw material
Description:	The carbon emission intensity factor associated with manufacture of product, k
Source of data	See Table 4
Measurement procedures	n/a
Comments:	

Data/parameter	$C_{TRANSPORTk}$
Data unit	t C emitted/t C raw material • km
Description:	The carbon emission intensity factor associated with the transport of raw material by transportation type of product, k
Source of data	See Table 4
Measurement procedures	n/a
Comments:	

Data/parameter	$d_{TRANSPORTk}$
Data unit	km
Description:	The distance transported by transportation type, *k*.
Source of data	Estimated based on Heath et al. 2006 Supplementary
Measurement procedures	n/a
Comments:	

Data/parameter	$\Delta C_{EMITTRANSPORT,t}$
Data unit	t C yr^{-1}
Description:	The annual fossil fuel emissions associated with the transport of raw material
Source of data	Heath et al. 2006 Supplementary
Measurement procedures	n/a
Comments:	Variables used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$G_{AG,i,t}$
Data unit	t d.m. ha^{-1} yr^{-1}
Description:	Annual increment rate in aboveground biomass (t d.m. ha^{-1} yr^{-1}), in polygon, *i*,

Source of data	Modeled (See Section 8 & 9)
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$G_{BG,i,t}$
Data unit	t d.m. ha^{-1} yr^{-1}
Description:	Annual increment rate in belowground biomass (t d.m. ha^{-1} yr^{-1}), in polygon, i,
Source of data	Calculated from G_{AG} and R_i
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$LBL_{NATURALi,t}$
Data unit	t d.m. yr^{-1}
Description:	Annual loss of live tree biomass due to natural mortality in polygon, i; t d.m. yr^{-1}
Source of data	Modeled (See Section 8 & 9)
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$LBL_{FELLINGSi,t}$
Data unit	t d.m. yr^{-1}
Description:	Annual loss of live tree biomass due to commercial felling in polygon, i; t d.m. yr^{-1}
Source of data	Modeled (See Section 8 & 9)
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$LBL_{OTHERi,t}$
Data unit	t d.m. yr^{-1}
Description:	Annual loss of live tree biomass from incidental sources in polygon, i; t d.m. yr^{-1}
Source of data	Modeled (See Section 8 & 9)
Measurement procedures	n/a

Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$LB_{i,t}$
Data unit	t d.m. yr^{-1}
Description:	Average live tree biomass in polygon, i, for year, t
Source of data	Calculated from $G_{i,t}$
Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$f_{BSL,NATURAL,i,t}$
Data unit	unitless; $0 \leq f_{NATURAL,i,t} \leq 1$
Used in:	Equation 7, Section 8
Description:	The annual proportion of biomass that dies from natural mortality in forest type analysis unit or polygon, i, year, t.
Source of data	Literature reports, and/or inventory data.
Measurement procedures	
Comments:	

Data/parameter	$f_{BSL,HARVEST,i,t}$
Data unit	unitless; $0 \leq f_{BSL,HARVESTi} \leq 1$
Used in:	Equation 8, Section 8
Description:	The proportion of biomass removed by harvesting from polygon, i, in year, t.
Source of data	Literature reports, and/or inventory data.
Measurement procedures	
Comments:	

Data/parameter	$f_{BSL,DAMAGE,i,t}$
Data unit	unitless; $0 \leq f_{BSL,DAMAGE,i,t} \leq 1$
Used in:	Equation 9, Section 8
Description:	The proportion of additional biomass removed for road and landing construction in polygon, i, year, t
Source of data	Literature reports, and/or inventory data.
Measurement procedures	
Comments:	

Data/parameter	$f_{BSL,BLOWDOWN,i,t}$
Data unit	unitless; $0 \leq f_{BSL,BLOWDOWN,i,t} \leq 1$
Used in:	Equation 12, Section 8
Description:	The annual proportion of live aboveground tree biomass subject to blowdown in polygon, i, year, t.
Source of data	Literature reports, and/or inventory data.
Measurement procedures	
Comments:	

Data/parameter	$f_{BSL,SNAGFALLDOWN,i,t}$
Data unit	unitless; $0 \leq f_{BSL,SNAGFALLDOWN,i,t} \leq 1$
Used in:	Equations 12 & 16, Section 8
Description:	The annual proportion of snag biomass in polygon, i, year, t, that falls over and thus is transferred to the LDW pool.
Source of data	Literature reports, and/or inventory data.
Measurement procedures	
Comments:	

Data/parameter	$f_{BSL,lwDECAY,i,t}$
Data unit	unitless; ; $0 \leq f_{BSL,lwDECAY,i,t} \leq 1$
Used in:	Equation 13, Section 8
Description:	The annual proportional loss of lying dead biomass due to decay, in polygon i, year, t,
Source of data	Literature reports, and/or inventory data.
Measurement procedures	
Comments:	

Data/parameter	$f_{BSL,SWDECAY,i,t}$
Data unit	unitless; $0 \leq f_{BSL,SWDECAY,i,t} \leq 1$
Used in:	Equation 16, Section 8
Description:	The annual proportional loss of snag biomass due to decay, in polygon, i, year, t.
Source of data	Literature reports, and/or inventory data.
Measurement procedures	
Comments:	

Data/parameter	$SNAG_{BSL,i,t}$

Data unit	t d.m. yr^{-1}
Description:	The total amount of snag mass in polygon i, year, t
Source of data	Calculated in equations 14b, 15,16
Measurement procedures	
Comments:	

Data/parameter	$DBG_{,i,t}$
Data unit	t d.m. yr^{-1}
Description:	The total quantity of dead belowground biomass accumulated in polygon i since the project start; t biomass.
Source of data	Calculated in equations 17b, 17c,17d (Section 8); Calculated in equations 45b, 45c,45d (Section 9)
Measurement procedures	Modeled.
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{PERMHWP1,t}$
Data unit	t C yr^{-1}
Used in:	The calculation of the annual change in the carbon stored in harvested wood products (HWP), $\Delta C_{PRJ,HWP,t}$,
Description:	Annual harvested carbon that remains in permanent storage after conversion to wood products during primary processing
Source of data	Calculated in equation 19 (Section 8) and equation 47 (Section 8)
Measurement procedures	
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{PERMHWP2,t}$
Data unit	t C yr^{-1}
Used in:	The calculation of the annual change in the carbon stored in harvested wood products (HWP), $\Delta C_{HWP,t}$,
Description:	Annual harvested carbon that remains in permanent storage after accounting for secondary processing of the residue carbon (biomass) generated from primary processing
Source of data	Calculated in equation 24 (Section 8) and equation 52 (Section 9)
Measurement procedures	
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{EMITFOSSIL,t}$
Data unit	t C yr^{-1}
Used in:	The calculation of the annual change in the carbon stored in harvested wood products (HWP), $\Delta C_{HWP,t}$,
Description:	Fossil fuel emissions from harvesting (logging and log transport) and processing of the various wood products.
Source of data	Calculated in equation 25 (Section 8) and equation 53 (Section 9)
Measurement procedures	
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$B_{RESIDUAl,t}$
Data unit	t d.m. yr^{-1}
Used in:	The calculation of $\Delta C_{PERMHWP2,t}$
Description:	The total residual biomass remaining in year t after primary product processing
Source of data	Calculated in equation 22 (Section 8) and equation 50 (Section 9)
Measurement procedures	
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$B_{BARK,t}$, $B_{COARSE,t}$, $B_{FINE,t}$
Data unit	t d.m. yr^{-1}
Used in:	The calculation of $B_{RESIDUAl,t}$
Description:	The biomass allocated to secondary processing of bark, and coarse and fine residuals, in year, t
Source of data	Calculated in equations 23a-c (Section 8) and equations 51a-c (Section 9)
Measurement procedures	
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$f_{PROCESSc}$, and $f_{PROCESSf}$
Data unit	Unitless
Description:	The process efficiency of coarse and fine residuals
Used In:	The calculation of $\Delta C_{PERMHWP2,t}$
Source of data	A default value of 85 % can be used (Perlack, Wright, Turhollow, Graham, Stodkes, & Erback, 2005) if project-specific values are not available.

Measurement procedures	n/a
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{EMITHARVEST,t}$
Data unit	t C yr^{-1}
Used in:	The calculation of $\Delta C_{EMITFOSSIL,t}$
Description:	Annual fossil fuel emissions associated with harvesting of raw material.
Source of data	Calculated in equation 26 (Section 8) and equation 54 (Section 9)
Measurement procedures	
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{EMITMANUFACTURE,t}$
Data unit	t C yr^{-1}
Used in:	The calculation of $\Delta C_{EMITFOSSIL,t}$
Description:	Annual fossil fuel emissions associated with the manufacturing of raw material.
Source of data	Calculated in equation 27 (Section 8) and equation 55 (Section 9)
Measurement procedures	
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	$\Delta C_{EMITTRANSPORT,t}$
Data unit	t C yr^{-1}
Used in:	The calculation of $\Delta C_{EMITFOSSIL,t}$
Description:	Annual fossil fuel emissions associated with the transport of raw material.
Source of data	Must be calculated after consideration of the transport distance from harvest to processing facility, and the means of transportation (after Heath et al. 2006 Supplementary). An example of calculation steps is provided in Section 8.
Measurement procedures	
Comments:	Variable used in both baseline (BSL) and project (PRJ) scenario, values may be different

Data/parameter	LE_y

Data unit	t CO2e yr^{-1}
Used in:	The calculation of Market Leakage (Option 1)
Description:	the project market leakage in year, y
Source of data	Calculated in Section 10.2, Option 1
Measurement procedures	
Comments:	

Data/parameter	SE_y
Data unit	t CO2e yr^{-1}
Used in:	The calculation of Market Leakage (Option 2)
Description:	The project market leakage in year, y
Source of data	Calculated in Section 10.2, Option 2
Measurement procedures	
Comments:	

Data/parameter	MLF_y
Data unit	Unitless
Used in:	Calculation of LE_y in year, y
Description:	The project market leakage
Source of data	Calculated in Section 10.2
Measurement procedures	
Comments:	

Data/parameter	$BC_{hv, n}$
Data unit	t CO2e yr^{-1}
Used in:	Calculation of SE_y
Description:	The estimated average baseline amount of onsite carbon harvested in reporting period, n (prior to delivery to a mill).
Source of data	Calculated in Section 10.2
Measurement procedures	
Comments:	

Data/parameter	$AC_{hv, n}$
Data unit	t CO2e yr^{-1}
Used in:	Calculation of SE_y

Description:	The actual onsite carbon harvested in reporting period, n (prior to delivery to a mill).
Source of data	Calculated in Section 10.2
Measurement procedures	
Comments:	

Data/parameter	$ER_{y,GROSS}$
Data unit	$t\ CO2e\ yr^{-1}$
Used in:	Calculation of LE_y
Description:	The gross difference in the overall annual carbon change between the baseline and project scenarios in year, y
Source of data	Calculated in equation 57
Measurement procedures	
Comments:	

Data/parameter	$ER_{y,}$
Data unit	$t\ CO2e\ yr^{-1}$
Used in:	Calculation of VCU_y
Description:	The net GHG emissions reductions and/or removals in year y (the overall annual carbon change between the baseline and project scenarios, net all discount factors except the permanence buffer)
Source of data	Calculated in equation 58
Measurement procedures	
Comments:	

Data/parameter	$VCU_{y,}$
Data unit	$t\ CO2e\ yr^{-1}$
Description:	Amount of Verified Carbon Units the project estimates are available for issuance and sale in year 'y'
Source of data	Calculated in equation 59
Measurement procedures	
Comments:	

Data/parameter	E_M
Data unit	%
Used in:	The calculation of uncertainty factor (Section 11.4)

Description:	An estimate of model error based on the relative area-weighted difference between of model-predicted values of carbon storage and those values measured in field plots
Source of data	Model output and field data
Measurement procedures	
Comments:	

Data/parameter	E_I
Data unit	%
Used in:	The calculation of uncertainty factor(Section 11.4)
Description:	An estimate of Inventory sampling error calculated as the 90% confidence limit of the area-weighted differences between the model-predicted values of carbon storage and those values measured in field plots
Source of data	Model output and field data
Measurement procedures	
Comments:	

Data/parameter	E_P
Data unit	%
Used in:	The calculation of uncertainty factor (Section 11.4)
Description:	An estimate of total project error based sum of the model and inventory error terms
Source of data	Model output and field data
Measurement procedures	
Comments:	

Data/parameter	$ER_{y,ERR,}$
Data unit	Unitless
Used in:	Calculation of VCU_y
Description:	The uncertainty factor calculated for year 'y' in Section 11.4
Source of data	Calculated in Section 11.4
Measurement procedures	
Comments:	

Data/parameter	$BR_{y,}$
Data unit	t CO2e yr^{-1}

Used in:	Calculation of VCU_y
Description:	Estimated VCU-equivalent tCO_2e issued to the VCS Buffer Pool in year, y.
Source of data	Calculated using the latest version of the VCS AFOLU Non-Permanence Risk Tool
Measurement procedures	
Comments:	

13 Monitoring Description

The objective of the project monitoring program is to reliably monitor changes in carbon stocks related to the calculation of VCU's prior to each verification. In particular, the program will monitoring changes in spatial forest inventory conditions and collect field data on carbon stocks to compare against modeled carbon stocks and to calculate an uncertainty factor.

13.1 Project Monitoring Requirements

The project shall develop and maintain an up to date monitoring plan which includes:

1. Spatial inventory change monitoring procedures

2. Carbon stock field plot sampling monitoring procedures

3. Standard Operating Procedures (SOPs) for monitoring activities

4. Quality Control/Quality Assurance and Data Archiving procedures

These elements shall meet the requirements described in the sections below.

The results of implementing the monitoring plan shall be produced in a project monitoring report for each monitoring period; prior to each verification.

13.2 Monitoring Annual Spatial Inventory Changes

Project proponents will undertake and document annual monitoring to identify and update spatial changes in the forest inventory data (i.e. changes in forest polygons due to planned or unplanned project activities and natural disturbances which change the classification of spatial areas within the project boundary).

Projects will undertake remote and ground-based monitoring (for example: satellite and aerial photography, aerial observation, ground observation, aerial and ground-based GPS mapping, etc.) to identify and update inventory data for:

a. Natural disturbance events > 4ha (i.e. fires, pest & disease outbreaks, slides and other disturbances;
b. Planned project activities (i.e. harvests, road construction, reforestation, etc.); and

c. Unplanned man-made disturbances (for example, non-*de minimis* illegal or unplanned harvests).

Annual spatial monitoring activities will be documented and dated, and inventory data updates identified by date or other notations.

13.3 Carbon Stock Monitoring Field Plot Sampling Design and Stratification

13.3.1 Stratification for Field Plot Sampling:

When an area is not homogeneous, stratification generally reduces monitoring costs by grouping areas with low variation in carbon stocks (Pearson et al. 2007).

Stratification for monitoring sample design should be consistent with that employed for the calculation of carbon stocks in the baseline (Section 8) and project (Section 9) scenarios.

The project proponent has the option to further stratify modeled polygons or analysis units to facilitate efficient field carbon stock monitoring. In particular, projects may need to further stratify modeled polygons or analysis units to gain sampling representation within analysis unit age classes. For example, an analysis unit might include similar forest type polygons that range from 40-200 years. For monitoring plot sampling, the analysis unit would likely need to be stratified into age classes with similar stand carbon content.

Any stratification undertaken for monitoring purposes shall be documented and justified, including documenting any variation from stratification made for modeling in Section 8 and 9. Monitoring stratification may be updated based on monitoring results (see Section 13.7.1).

13.3.2 Field Plot Sampling Framework

The objective of the field plot network is to determine the statistical accuracy of the modeled carbon stocks by polygon or analysis unit. The field-measured values of the tree biomass and dead organic matter pools described below will be compared against the associated modeled values described in Section 9 to determine error in the modeled value for a particular polygon or analysis unit (see Section 9.2). Some deviation of the field-measured values from the modeled values can be expected, which is then accounted for in the uncertainty factor calculation (Section 11.4).

The "Sourcebook for Land Use, Land-Use Change and Forestry Projects" (Pearson, Walker, & Brown, 2005) provides methods and procedures to generate accurate and precise estimates of changes in carbon stocks. (Pearson, Brown, & Birdsey, 2007). Project proponents can substitute other comparable published and peer-reviewed forest carbon sampling and measurement manuals and techniques if they are demonstrated to be applicable and consistent with the data collection requirements of this methodology.

Type and Number of Sampling Plots

Plot Type

For forestry activities, both permanent and temporary sampling plots have been used to estimate changes in carbon pools (Pearson, Brown, & Birdsey, 2007). Permanent sample plots are regarded as statistically more efficient for estimating changes in forest-carbon stocks over

time than temporary plots because there is high covariance between observations in successive sampling events (Pearson, Brown, & Birdsey, 2007). Moreover, the use of permanent plots allow for efficient verification. Hence, the majority of plots used in the monitoring program should be geo-referenced, permanently re-measurable plots with all trees marked. Geo-referenced temporary plots may also be used for efficient supplemental data collection.

Number of Plots, Precision, and Sample Size

The proponent will develop a plot network with representation in every polygon or analysis unit[37] (based on the primary stratification method identified in Section 8 and used throughout the project calculations) and a design target of establishing enough plots such that the estimate of carbon stocks across all polygon or analysis units will lie within 10 percent of the true value of the mean at the 90-percent confidence level[38].

Project proponents may develop initial estimates of the number of plots needed for monitoring using variance estimates from existing or comparable forest inventory data and following procedures outlined in (Pearson et al. 2007), or other peer reviewed published methods.

For practical purposes it is recognized that on large or complex project areas the plot network may need to be developed across several years (no longer than 5 years) to approach the target level of precision. Samples sizes should be evaluated for suitability following the initial monitoring period and then adjusted as appropriate to achieve the desired level of precision.

Plot Sampling Design

Plot Layout

Permanent sample plots can be located at random or systematically using a plot grid. The latter approach results in greater precision if some areas within polygons have higher carbon content than others (Pearson, Brown, & Birdsey, 2007).

Size and Shape of Sample Plots

Plot shape and size can be determined by the project proponent based on local common practice and the most suitable methods for the project conditions, so long as the procedures are fully documented in project SOP's and the results provide verifiable statistical sampling as required by this methodology. Projects may consider consistent fixed area square or circular plots, or consider a variable nested plot area design which may be better suited to highly variable stand diameter conditions ((see (Pearson, Brown, & Birdsey, 2007)).

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[37] See Section 11.4 for additional clarification on plot requirements. If using a polygon stratification, representation of each polygon is required; if using an analysis unit stratification, representation of each analysis unit is required (and not each polygon within the analysis unit).
[38] The uncertainty factor calculation in Section 11.4 accounts for, and penalizes the project credits for higher uncertainty error, and hence this target is provided as guidance for plot network design to achieve the lowest uncertainty factor.

Measurement and Data Analysis Techniques

Trees

Although the tree carbon stock is estimated most accurately and precisely by direct methods (whereby all the trees in a sample plot above a minimum diameter are harvested, dried and weighed), it is expected this approach will be impractical for most projects. Therefore, tree biomass should be estimated from allometric biomass equations that predict aboveground biomass from mathematical relationships between DBH and/or height and species. Allometric biomass equations have been published for many species and regions. The project proponent should select the most appropriate equations by determining which published equations are most representative of the species and conditions on the project site. Other factors that should be taken into account include the relative statistical accuracy of the equations, and the number and size range of the samples used to generate the equation parameters.

All living trees within a sample plot with DBH ≥ 5cm must be measured for height (m) and diameter (cm) at breast height (1.3m).

Tree-level measurements (kg biomass per tree) must be converted to area-based stand-level measurements (t ha^{-1}). A description of the steps and equations employed in the process are provided in Section 9.2.1.

Dead Organic Matter

An efficient method for sampling lying dead wood is the line-intersect (Pearson, Brown, & Birdsey, 2007). For example, (Harmon & Sexton, 1996) use a minimum 100m line length[39]. Placing two 50-m sections of line at right angles across the plot center also is an efficient and valid approach. To allow re-measurement of the same "dead wood plot", it is important to accurately record where the line was placed. The diameters of all pieces of wood that intersect the line are measured and the density class noted. A minimum diameter for measurement is defined in this methodology as 5 cm (Harmon & Sexton, 1996).

Each piece of dead wood will be assigned to one of three density classes, sound (1), intermediate (2), and rotten (3) (details below). The volume per unit area is calculated for each density class, c, as:

$$V_{LDW,c} = \pi^2 * [\,(d_1^2 + d_2^2 \ldots d_n^2)/8L\,] \tag{60a}$$

where:

d_1, d_2, d_n = diameter (cm) of each of n pieces intersecting the line, and

L = the length of the line (100 m default (Harmon, et al., 1986).

The mass of LDW in density class, c (t ha^{-1}), is:

$$M_{LDW,c} = V_{LDW,c} * D_{LDW,c} \tag{60b}$$

where:

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[39] Other sample line lengths may be used if referenced from other published sources (i.e. see (Harmon et al, 2008)).

$V_{LDW,c}$ = the volume per unit area calculated for each density class, *c*, as calculated in 60a.

$D_{LDW,c}$ = the density of LDW in density class, *c* (t d.m. m^{-3})

The total mass of LDW in each plot summed over all density classes (t ha^{-1}) is:

$$DOM_{LDW} = \sum M_{LDW,c} \qquad\qquad\qquad (60c)$$

where:

$M_{LDW,c}$ = the mass of LDW in density class, *c* (t ha^{-1}), is as calculated in 60b.

A key step in this method is classifying the dead wood into its correct density class and then sampling a sufficient number of logs in each class to derive a reasonable estimate of wood density. Ideally at least 10 logs should be sampled for each density class (Pearson, Brown, & Birdsey, 2007). For a given piece of dead wood, a field characterization of its density class can be made by striking it with a strong sharp blade. If the blade bounces off it is classed as sound, if it enters slightly it is of intermediate density, and if the wood falls apart it is rotten. Samples of dead wood in each class will then be collected to determine their density in the laboratory, after drying for 48 hours. Mass of dead wood is calculated as the product of volume per density class and the wood density for that class (as per equations 60 a-c)[40].

The total mass of lying dead wood for a given polygon should be calculated as the average of all transects measured for that polygon. This value is then used for calculations of carbon storage in dead organic matter ($DOM_{LDW,l,t}$), as described in Section 9.2.1.

Standing dead wood should be measured in the same plots as used for measuring live trees. Snags suitability is defined using the same criteria for live trees. However, measurement records will differ slightly from those for live trees, depending on the degree to which branches and twigs are present. If the snag possesses branches and twigs and its structure resembles a live tree (but without leaves), this should be indicated in the field data records. From the measurement of DBH, the amount of biomass can then be estimated using the appropriate allometric biomass equation and subtracting the biomass of leaves. Snags may possess only a fraction of their full complement of small and large branches, only large branches, or no branches at all. These conditions will be recorded in the field measurements. Branches will then be classified in proportion to the size of the standing dead tree so that the total biomass can be reduced accordingly to account for less of the dead tree remaining. When a tree has no branches and is only the bole, biomass can be estimated from measurements of its basal diameter and height and an estimate of top diameter.

Once the biomass of standing dead trees within a plot has been calculated, the tree-level measurements (kg biomass per tree) must be converted to area-based stand-level measurements (t ha^{-1}) by summing the total mass (aboveground + belowground) of all the standing dead trees within a sample plot (converting kg to t) and dividing the sum by the plot area in ha. All plots within a particular polygon should be averaged to get an average estimate

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[40] Alternatively, projects may use other published decay sampling classifications and methods, and in particular may find useful additional methods outlined in Harmon et al. 2008. Woody Detritus Density and Density Reduction Factors for Tree Species in the United States: A Synthesis. USDA Forest Service GTR NRS-29.

of stand-level live biomass (t ha^{-1}). This value is an estimate of the average snag biomass variable (**DOM$_{SNAG,i,t}$**) used in Section 9.2.1.

13.4 Quality Assurance/Quality Control (QA/QC) Methods

The monitoring plan or associated SOPs should include QA/QC procedures for: (1) collecting reliable field measurements; (2) verifying laboratory procedures; (3) verifying data entry; and (4) data archiving.

QA/QC for Field Measurements

A set of Standard Operating Procedures (SOP) shall be developed for field carbon measurements. The SOPs will detail all phases of the field measurements so that the measurements can be repeated reliably. A document will be produced and filed with the project documents verifying that all QA/QC steps have been taken.

Field crews shall be trained in all field data collection SOPs and records of training kept by the project proponent.

An audit program for field measurements and sampling shall be established. A typical audit program should consist of three types of checks. During a hot check, auditors observe members of the field crew during actual data collection (this is primarily for training purposes). Cold checks occur when field crews are not present for the audit. Blind checks represent the complete re-measurement of a plot by the auditors. Hot checks allow the correction of errors in technique. Measurement variance can be calculated through blind checks.

At a minimum, 10% of the measured field plots will be check-cruised using blind checks with 100% re-measurement of all variables. Minimum thresholds in measurement error are as follows:

1. DBH (standing live and dead): +/- 10% standard error at 90% confidence interval
2. Height (standing live and dead): +/- 10% standard error at 90% confidence interval
3. Tree Count: +/- 10% standard error at 90% confidence interval

These are minimum thresholds for monitoring plot field accuracy, and will require re-measurement or re-establishment of plots as necessary to meet these requirements.

QA/QC for Laboratory Measurements

SOPs will be prepared and followed for each laboratory analyses. Typical steps in the SOP for laboratory measurements will include calibrating standards for instruments used.   Where practical, 10 percent of the samples will be re-analyzed/re-weighed following the check cruise thresholds outlined above.

QA/QC for Data Entry

Projects shall develop procedures to ensure proper entry of data and conversion between paper and electronic formats. Data anomalies will be resolved using the original field data, or re-measurement of data if feasible. If there are anomalies that cannot be resolved, the plot will be omitted from the analysis.

Data Archiving

The project will provide data archiving SOPs which provide procedures for securely retaining and maintaining the following records for each monitoring period for 2 years past the duration of the project:

1. Original copies of the field measurement, check plots, laboratory data, and related data summaries will be maintained in their original and electronic form
2. Copies of all monitoring data analyses, models, model input and output files, carbon calculations required for this methodology, GIS inventory dated by year, and copies of the monitoring reports.
3. Records of the version and relevant change history of software or data storage media changed between monitoring periods.

13.5 Leakage Monitoring

Activity shifting leakage monitoring requires reporting the 'demonstration of activity shifting' annually, as required by VCS, and as per the methods outlined in section 10.1.

Market leakage monitoring requirements depend on the selected option:

1. Market Leakage Option 1 – VCS Default Market Leakage Discount Factors:
   a. No further leakage monitoring required
2. Market Leakage Option 2 – CAR Market Leakage Factor
   a. The project proponent will annually update the leakage calculation using the most current project plan harvest levels.
3. Market Leakage Option 3 – Leakage Assessment Tool
   a. Project proponents shall re-evaluate the data and calculations at each verification.

13.6 Frequency of monitoring

Permanent sample plots shall be re-measured at intervals of ≤ 5 years.

Spatial monitoring and leakage monitoring, are to be monitored annually.

13.7 Use of Monitoring Data to Update Carbon Stock Calculations

Data gathered through the monitoring process shall be used to:

1. Update the project inventory data and related modeling and monitoring stratification as per Section 9.2 and 13.7.1;
2. Update leakage calculations in Section 10;
3. Update the inventory error estimates used in the calculation of the uncertainty factor described in Section 11.4; and,
4. Update and improve calculations of carbon stocks in Section 9 and possibly Section 8 as described in Section 9.2.

13.7.1   Updating of Monitoring Polygons

The ex-post stratification and polygon assignment to specific analysis units (see Section 13.2) shall be updated on an annual basis and, at minimum prior to each verification, for any of the following reasons:

1. Errors in the inventory from field sampling or other monitoring. If the criteria used to allocate a polygon are not in accordance with field evidence, that polygon should be updated and re-assigned accordingly if necessary. Any non-*de minimis* updates due to errors in the inventory will require recalculation of both the annual project emissions (Section 9.3) and the annual baseline emissions (Section 8.2) prior to the next verification;
2. Changes to spatial inventory from monitoring for natural disturbance and planned/unplanned project activities. Updates will be made for any monitored event that affects the criteria used to define a given polygon or analysis unit in the project inventory. Note that disturbance or activity events may result in creation of a new polygon, or an age reclassification for the stand, and/or a re-assignment of the polygon. These updates only affect the calculation of carbon emissions from the project scenario (Section 9.3).
3. Established polygons may be merged if the original justification for their separate creation no longer applies. These updates only affect the calculation of carbon emissions from the project scenario (Section 9.3).

14 Data and Parameters Monitored

The following parameters must be monitored during the project activity. When applying all relevant equations provided in this methodology for the ex-ante calculation of net anthropogenic GHG removals by sinks, project participants shall provide transparent estimates for the parameters that are monitored during the crediting period. These estimates shall be based on measured or existing published data where possible and project participants must retain a conservative approach: if different values for a parameter are equally plausible, a value that provides the least over-estimation of net anthropogenic GHG removals by sinks must be selected.

Data/parameter	$A_{PRJ,i,}$
Data unit	Ha
Used in	Various equations in equation #32-60
Description:	Area of forest land in polygon, *i*
Source of data	Monitoring of polygons and stand boundaries shall be done preferably using a Geographic Information System (GIS), which allows for integrating data from different sources (including GPS coordinates and Remote Sensing data).
Measurement procedures	
Comments:	

Data/parameter	$A_{p,i,t}$
Data unit	m^2
Used in:	Calculation of mean aboveground biomass B_{AG} and DOM_{SNAG} in Section 13.2 and 9.2.1.

Description:	Area of sample plot in polygon, i, at time, t
Source of data	Recording and archiving of size of sample plots
Measurement procedures	
Comments:	

Data/parameter	$DBH_{,t}$
Data unit	cm
Used in:	Calculation of mean aboveground biomass B_{AG} in Section 13.2 and 9.2.1.
Description:	Diameter at breast height measured for each tree in the sample plots at time, t
Source of data	Field measurements in sample plots
Measurement procedures	Typically measured at 1.3m height above ground. Measure all trees above minimum DBH (5 cm) in the sample plots that result from the IFM project activity.
Comments:	

Data/parameter	$Height_{,t}$
Data unit	m
Used in:	Calculation of mean aboveground biomass B_{AG} in Section 13.2 and 9.2.1.
Description:	Tree height measured for each tree in the sample plots at time, t
Source of data	Field measurements in sample plots
Comments:	

Data/parameter	$L_{,t}$
Data unit	m
Used in:	Calculation of mean mass of DOM_{LDW} in Section 13.2 and 9.2.1.
Description:	Length of the transects to used determine volume of lying dead wood in the sample plots at time, t (default 100m)
Source of data	Field measurements
Measurement procedures	
Comments:	

Data/parameter	$d_{n,t}$
Data unit	cm
Used in:	Calculation of mean mass of DOM_{LDW} in Section 13.2 and 9.2.1.

Description:	Diameter of each piece n of dead wood along the transects in the sample plots at time, t
Source of data	Field measurements
Measurement procedures	Measured using the line-intersect method (Section 13).
Comments:	

Data/parameter	$D_{LDW,c,i,t}$
Data unit	$(t\ d.m.\ m^{-3})$
Used in:	Calculation of mean mass of DOM_{LDW} in Section 13.2 and 9.2.1.
Description:	Density of dead wood in density class, c along the transect in polygon, i, at time, t
Source of data	Field measurements
Measurement procedures	Measured using the line intersect method (Section 13).
Comments:	

Data/parameter	$N_{,t}$
Data unit	unitless
Used in:	Calculation of mean mass of DOM_{LDW} in Section 13.2 and 9.2.1.
Description:	Total number of wood pieces intersecting transects in the sample plots at time, t
Source of data	Field measurements
Measurement procedures	Measured using the line-intersect method (Section 13).
Comments:	

Data/parameter	$B_{AGi,t}$
Data unit	$t\ d.m.\ ha^{-1}$ (d.m. = dry matter)
Used in:	Calculation of carbon stocks in above- and belowground living tree biomass in equations 28b & 28c, Section 9.2.1.
Description:	Average total aboveground biomass in polygon, i, for year, t
Source of data	Calculated from $Height_{i,t}$, $DBH_{i,t}$, and $A_{p,i,t}$
Measurement procedures	
Comments:	Calculated

Data/parameter	$B_{BGi,t}$
Data unit	$t\ d.m.\ ha^{-1}$ (d.m. = dry matter)
Used in:	Calculation of carbon stocks in above- and belowground living tree biomass in equations 28b & 28c, Section 9.2.1.
Description:	Average total belowground biomass in polygon, i, for year, t

Source of data	Estimated from $B_{AGi,t}$
Measurement procedures	
Comments:	Estimated

Data/parameter	$B_{TOTAL,i,t}$
Data unit	t d.m. ha^{-1} (d.m. = dry matter)
Used in:	Calculation of carbon stocks in above- and belowground living tree biomass in equation 28c, Section 9.2.1.
Description:	Average total live biomass in polygon, *i,* for year, *t*
Source of data	Calculated from $B_{AGi,t}$ and $B_{BGi,t}$
Measurement procedures	
Comments:	Calculated

Data/parameter	$DOM_{LDW,i,t}$
Data unit	t d.m. ha^{-1} (d.m. = dry matter)
Used in:	Calculation of carbon stocks in dead organic matter (equation 28e, Section 9.2.1)
Description:	Average mass of dead organic matter contained in lying dead wood in polygon, *i,* year, *t*
Source of data	Calculated from $L_{,i,t}$, $d_{n,i,t}$, $D_{LDW,c,i,t}$, and $N_{i,t}$
Measurement procedures	
Comments:	Calculated

Data/parameter	$DOM_{SNAG,i,t}$
Data unit	t d.m. ha^{-1} (d.m. = dry matter)
Used in:	Calculation of carbon stocks in dead organic matter (equation 28e, Section 9.2.1)
Description:	Average mass of dead organic matter contained in standing dead wood in polygon, *i,* year, *t*
Source of data	Calculated from $Height_{i,t}$, $DBH_{i,t}$, and $A_{p,i,t}$ of dead trees measured in sample plots described in Section 13
Measurement procedures	
Comments:	Calculated

Data/parameter	$f_{PRJ,NATURAL,i,t}$
Data unit	unitless; $0 \leq f_{NATURAL,i,t} \leq 1$
Used in:	Equation 35, Section 9

Description:	The annual proportion of biomass that dies from natural mortality in polygon, *i*, year, *t*.
Source of data	Permanent sample plots in similar stand types, literature reports, and inventory data
Measurement procedures	
Comments:	

Data/parameter	$f_{PRJ,HARVEST,i,t}$
Data unit	unitless; $0 \leq f_{PRJ,HARVESTIi} \leq 1$
Used in:	Equation 36, Section 9
Description:	The proportion of biomass removed by harvesting from polygon, *i*, in year, *t*.
Source of data	Permanent sample plots in similar stand types, literature reports, and inventory data
Measurement procedures	
Comments:	

Data/parameter	$f_{PRJ,DAMAGE,i,t}$
Data unit	unitless; $0 \leq f_{PRJ,DAMAGE,i,t} \leq 1$
Used in:	Equation 37, Section 9
Description:	The proportion of additional biomass removed for road and landing construction in polygon, *i*, year, *t*
Source of data	Permanent sample plots in similar stand types, literature reports, and inventory data
Measurement procedures	
Comments:	

Data/parameter	$f_{PRJ,BLOWDOWN,i,t}$
Data unit	unitless; $0 \leq f_{PRJ,BLOWDOWN,i,t} \leq 1$
Used in:	Equation 40, Section 9
Description:	The annual proportion of live aboveground tree biomass subject to blowdown in polygon, *i*, year, t.
Source of data	Permanent sample plots in similar stand types, literature reports, and inventory data
Measurement procedures	
Comments:	

Data/parameter	$f_{PRJ,SNAGFALLDOWN,i,t}$
Data unit	unitless; $0 \leq f_{PRJ,SNAGFALLDOWN,i,t} \leq 1$

Used in:	Equation 40 & 44, Section 9
Description:	The annual proportion of snag biomass in polygon, i, year, t, that falls over and thus is transferred to the LDW pool.
Source of data	Permanent sample plots in similar stand types, literature reports, and inventory data
Measurement procedures	
Comments:	

Data/parameter	$f_{PRJ,lwDECAY,i,t}$
Data unit	unitless; ; $0 \leq f_{PRJ,lwDECAY,i,t} \leq 1$
Used in:	Equation 41, Section 9
Description:	The annual proportional loss of lying dead biomass due to decay, in polygon i, year, t,
Source of data	Permanent sample plots in similar stand types, literature reports, and/or inventory data
Measurement procedures	
Comments:	

Data/parameter	$f_{PRJ,SWDECAY,i,t}$
Data unit	unitless; $0 \leq f_{PRJ,SWDECAY,i,t} \leq 1$
Used in:	Equation 44, Section 9
Description:	The annual proportional loss of snag biomass due to decay, in polygon, i, year, t.
Source of data	Permanent sample plots in similar stand types, literature reports, and/or inventory data
Measurement procedures	
Comments:	

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